THE CIRCADIAN VARIATION OF PSYCHOPHYSIOLOGICAL REACTIVITY TO STRESS: A STUDY OF INDIVIDUAL DIFFERENCES

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NEBEL

UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES
4301 JONES BRIDGE ROAD
BETHESDA, MARYLAND 20814-4799

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Name of Candidate: Linda Nebel

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J. E. Singer — 25 Aug. 1994
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Committee Member — Date

Felix Strumwasser — 25 August 1994
Committee Member — Date

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Committee Member — Date

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Linda Nebel
Department of Medical & Clinical Psychology
Uniformed Services University of the Health Sciences

ABSTRACT

The Circadian variation of psychophysiological reactivity to stress: A study of individual differences:

Linda E. Nebel, Ph.D., 1994

Dissertation directed by: David S. Krantz, Professor, Department of Medical and Clinical Psychology

The present study assessed the circadian variation of cardiovascular and affective reactivity to stress, and performance. Thirty-five healthy males and females were administered a series of tasks in a within-subject design with sessions counterbalanced at 7:30 a.m. and 3:30 p.m. on separate days. Affective responses were greater during the AM as demonstrated by higher self-reported levels of "frustrated". However, attention and cardiovascular responses appear to be greater during the PM. Marginally significant effects revealed that the Continuous Performance Test (CPT), a test of attention, yielded more correct responses and a faster reaction time during the PM session while the number of omissions were greater during the AM session. Cardiovascular levels were higher during the PM session for heart rate (HR) and marginally higher for rate pressure product (RPP) and systolic blood pressure (SBP). Changes from rest to task revealed greater cardiovascular reactivity during the PM session for diastolic blood pressure (DBP) and SBP. These measures were also examined for interactions between time of day and circadian type. Subjects were classified as Morning or Evening subjects

based on the Morningness-Eveningness Questionnaire (Horne and Ostberg, 1976). Significant interactions were found for cardiovascular and affective measures in response to stress, but not for performance on the CPT. Overall, Morning subjects responded to stress more during the AM session whereas Evening subjects responded more during the PM session for levels of RPP and changes in RPP and SBP. Similarly, levels of "bored" and marginal levels of "interested", and changes in "bored", and marginal changes in "anxious", "frustrated", "happy", and "challenged" also interacted with circadian type. The existence of different patterns of stress responses depends upon circadian type and time of day and is discussed regarding methodological and health implications. Differences between Morning and Evening subjects were observed for self-report measures independent of time of day. Evening subjects rated themselves as more "frustrated", "irritated", "tired", and "bored", and less "happy". Evening subjects also reported greater levels of stress. Stress exposure is proposed as a mechanism by which circadian type (increased Eveningness) may be influenced.

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by

Linda E. Nebel

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DEDICATION

This dissertation is dedicated to John K. Nebel and Lauren Alana Nebel for their love and support.

In memory of Sandra Jochum whose work lives on in this research.

TABLE OF CONTENTS

TABLES

FIGURES

INTRODUCTION

The notion that organisms vary in their behavior and physiological processes depending upon the time of day has been recognized for centuries. However, the term "circadian rhythm" is relatively new and was first used by Halberg (1959) to characterize rhythms that last approximately 24 hours (Moore-Ede, Sulzman, and Fuller, 1982). A variety of psychological, behavioral, and physiological circadian rhythms have since been identified.

Although researchers sometimes control for the time of day when examining physiological and psychological responses to stress, whether and how the stress response varies across the day is not known. The present research examines psychophysiological and behavioral responses to stress at two time points during the day. In addition, individual differences that may contribute to variation across the day were also studied. Specifically, the "circadian type" of the individual may interact with the time of day to produce different responses. Circadian type refers to an individual's preferred times for engaging in a variety of mental and physical activities during the day (Horne and Ostberg, 1976). So-called "Morning" and "Evening" people may respond differently to stress depending upon what period of the day the stress occurs. Furthermore, a variety of physiological and psychological factors may contribute to a

greater vulnerability to stress at certain times of the day. These factors include cardiovascular, hormonal, and affective functioning that change in response to stress. Underlying physiological processes and perceptions of stimuli may vary across the day differently depending upon the circadian "type" of the individual, contributing to differing responses to stress.

Circadian Rhythms

Circadian rhythms are physiological processes that occur with cyclical variation, with each cycle lasting approximately twenty-four hours and occurring repetitively over time (Reinberg and Smolensky, 1983). However, psychological and behavioral factors may also exhibit circadian variation. These rhythms can be endogenous in origin, being controlled by an internal clock, whereas exogenous influences are controlled by "zeitgebers" or external time cues. The internal clock which is believed to drive circadian rhythms is the suprachiasmatic nucleus in the brain (Meijer and Rietveld, 1989). Strong evidence for the suprachiasmatic nucleus' role as pacemaker comes from transplantation studies. This research find that cells grafted into animals whose suprachiasmatic nucleus has been ablated take over the pacemaker functions. Humans also appear to operate under the influence of an oscillator

(Aschoff, 1965). External cues or exogenous factors can help to drive this oscillator. One such factor that can entrain circadian rhythms is the light-dark cycle. Wehr et al. (1993) exposed humans to long and short dark periods. They found that melatonin secretion, prolactin secretion, cortisol secretion, low temperature, and sleep were all found to be longer after long nights. These results remained even after long nights had ended and a constant routine of wakefulness and light was undertaken. Thus, many of rhythms are influenced by both endogenous and exogenous components (Moore-Ede, Sulzman, and Fuller, 1982).

A variety of these rhythms may also be related to the occurrence of clinical cardiovascular events (e.g. myocardial infarction and sudden death) and are reviewed later. Many physiological rhythms have been observed, with cardiovascular, endocrinological, and hematological factors showing distinct circadian variations (e.g. Millar-Craig, Bishop, and Raftery, 1978; Weitzman, Fukushima, Nogeire, Roffwarg, Gallagher, and Hellman, 1971; Rosing, Brakman, Redwood, Goldstein, Beiser, Astrup, and Epstein, 1970). In addition to physiological processes, psychological parameters, including negative affect and certain types of clinical psychopathology, have also been shown to vary rhythmically throughout the day (e.g Margraf, 1990). Finally, behavioral responses, such as performance measures,

also have been shown to vary cyclically (e.g. Folkard, Monk, and Lobban, 1978).

The idea that there are circadian differences in responses to stress derives from several different areas of research. First, evidence suggests that clinical cardiovascular events do not occur randomly throughout the day, but instead exhibit a distinct circadian variation (e.g., Muller, Stone, Turi, Rutherford, Czeisler, Parker, et al., 1985). These events are more likely to occur during the morning hours when cardiac demand (which varies as a function of blood pressure and heart rate) increases. Cardiovascular events can be affected by the increased demand associated with psychophysiological reactivity to mental stress (e.g., Krantz, Helmers, Bairey, Nebel, Hedges, and Rozanski, 1991). Cardiovascular reactivity is defined "in terms of heart rate, blood pressure, or other cardiovascular changes in response to stress, as opposed to measuring only resting levels of cardiovascular variables" (Krantz and Falconer, in press). Excessive reactivity can result in an increased demand upon the heart that may be related to the occurrence of clinical cardiac events (Krantz, Helmers, Bairey, Nebel, Hedges, and Rozanski, 1991). Therefore, cardiac demand associated with reactivity to stress may exhibit a circadian variation which mirrors that found for clinical cardiovascular events. Because

clinical events occur more frequently during the morning hours, reactivity to stress may also be the greatest during this time. To further support the possibility that there are circadian differences in reactivity to stress, there is evidence that psychological and physiological factors related to the stress response vary with the time of day, potentially contributing to greater reactivity during the morning hours.

Circadian Variation of Physiological Parameters

A variety of physiological factors show circadian variation. Blood pressure is commonly assessed in studies of both acute and chronic stress as a indicator of sympathetic activity. Several studies have examined the circadian variation of blood pressure (BP), and have observed a morning peak in blood pressure (e.g., Millar-Craig, Bishop, & Raftery, 1978; Floras, Jones, Johnston, Brooks, Hassan, & Sleight, 1978). Other studies show an afternoon BP peak (e.g., Wang, Wang, Zhang, Liu, Xue, Cornelissen, and Halberg, 1992) or no difference in BP levels across both time periods (e.g., Broadhurst, Brigden, Dasgupta, Lahiri, and Raftery, 1990). The studies reviewed here all allowed subjects to engage in their daily activities throughout the experimental session, and the majority also used intra-arterial measurement of BP, which

provides the most accurate measurement of BP levels. Whereas the time of peak BP may vary among these studies, a rise in blood pressure during the morning hours is a consistent finding. Similarly, the lowest BP values are found to be during the night, corresponding with sleep and low levels of activity.

One potential explanation of the varying circadian curves (i.e. morning vs. afternoon peaks) observed in these studies may be individual differences among the subjects. In a chronobiological study of blood pressure, subjects performed five home readings a day for a period of forty days, and results showed that all subjects displayed a circadian variation for either systolic blood pressure or diastolic blood pressure (De Scalzi, De Leonardis, Fabiano, and Cinelli, 1986). However, the rhythms varied depending upon the individual, and these researchers determined that generalizations should not be made regarding blood pressure curves. Instead, each individual should be assessed separately. This is particularly true when anti-hypertensive medication administration is based on the circadian variation of blood pressure (De Scalzi, et al., 1986). It is also possible that depending on the circadian type of the subjects used, differing circadian peaks might be observed.

Studies suggest that the circadian variation for blood

pressure is not strictly endogenous in nature, but instead that this variation is activity-driven (Pickering, 1993). Research shows that activity contributes more to the variation in blood pressure than time of day. This can be seen in studies of shift-workers which find that blood pressure is highest during periods of activity, regardless of time of day (Mann, Millar-Craig, Melville, Balasubramanian, and Raftery, 1979; Baumgart et al. 1989; Sundberg, Kohvakka, & Gordin, 1988).

Studies of blood pressure circadian rhythms in ambulatory patients vary widely in their methodology and, not surprisingly, show varying results. Some studies employ self-measurement of blood pressure, while others use automated blood pressure monitoring. The studies reviewed above primarily used intra-arterial measurement which provides the greatest level of reliability. The accuracy of these methods could vary widely, with self-measurement being the most susceptible to error. Furthermore, the activities the subjects are allowed to engage in during the study may also affect the results. For example, studies examining subjects during their daily life may produce results different from studies examining subjects confined to bed. Studies in daily life might give a better indication of how exogenous factors interact with endogenous factors to influence circadian rhythms, whereas studies of prone

subjects confined to bed may isolate endogenous influences. Furthermore, the number of measurements taken during the study can influence results of studies of circadian rhythms. Presumably, the greater the number of measurements taken during the period, the more reliable the results should be. These methodological criticisms regarding measurement and activities can be applied to any variable being measured concerning its circadian rhythm, not just blood pressure.

Studies have also examined the circadian rhythm of heart rate. Millar-Craig and colleagues (1978) found that heart rate during daily life rose in the morning hours, peaked at midday, and began to fall throughout the rest of the day. Similar results have been observed in other studies as well (Taillard, Sanchez, Lemoine, and Mouret, 1990).

While sympathetic activity, measured by heart rate and blood pressure (and catecholamines to be discussed later), appears to rise and peak during the morning hours, parasympathetic withdrawal also appears to take place during the morning. Vagal tone, a measure derived from heart rate variability, and related to respiration (Porges, McCabe, and Yongue, 1982), is used as a measure of parasympathetic activity. Furlan and colleagues (1990) examined the circadian variation of vagal tone in two separate populations. Vagal tone was measured in hospitalized

hypertensives and in healthy subjects during daily life. Vagal tone dropped during the morning hours and began to rise again at night (Furlan, Guzzetti, Crivellaro, Dassi, Tinelli, Baselli, Cerutti, Lombardi, Pagani, and Malliani, 1990). Thus, parasympathetic activity appears to decrease in the morning concurrently with the sympathetic surge, demonstrated by heart rate and blood pressure.

Endocrinological factors related to cardiovascular reactivity to stress have also been examined for circadian variation. Activation of the sympathetic nervous system leads to the release of the catecholamines from the adrenal medulla. In one study (Turton and Deegan, 1974) periodic blood draws, in coronary artery disease (CAD) patients undergoing cardiac catheterization, were performed to examine the circadian rhythms of epinephrine and norepinephrine. Subjects were restricted to bed to limit activities so that the endogenous rhythm could be examined. Epinephrine began to rise immediately upon waking, peaking later in the morning around 11:00 a.m. Norepinephrine began to rise later and peaked in the late morning hours. Activation of the sympathetic nervous system also leads to a cortisol response via activation of the adrenal cortex by pituitary hormones. Cortisol, studied in subjects under a restricted schedule in the laboratory, shows a similar circadian variation. Weitzman, Fukushima, Nogeire,

Roffwarg, Gallagher, and Hellman (1971) showed that each subject had several peak secretory episodes throughout the day. However, the peak in the frequency of these episodes occurred just following waking in the morning hours. These cortisol secretory episodes begin to increase before waketime, suggesting activity is not an essential component of this variation. Turton and Deegan (1974) also observed a peak in cortisol at 7:00 a.m., immediately following waketime in supine subjects.

Two other physiological variables related to cardiovascular functioning, and that change in response to stress, include platelet aggregability and fibrinolytic activity. These two physiological factors also show alterations during the morning hours. Tofler and colleagues (1987), under a controlled laboratory setting, examined platelet activity every three hours for a twenty-four hour period. The only significant change in platelet functioning occurred between the 6:00 a.m. and 9:00 a.m. sampling period. However, when subjects remained supine, or wake time was delayed, platelet aggregability did not increase. Consequently, the morning increase in platelet aggregability appears to be activity-driven or exogenous in nature. Fibrinolytic activity was also examined across the day. The lowest level of fibrinolytic activity occurred at 8:00 a.m., while peaks in activity occurred in the early evening (5:00

p.m. to 8:00 p.m.) (Rosing, Brakman, Redwood, Goldstein, Beiser, Astrup, and Epstein, 1970).

Circadian Variation of Psychological Parameters

Psychological factors have also been examined in their relation to time of day. Clinical findings suggest that the occurrence of panic attacks show a circadian rhythm. Although panic attacks have a biological component, they are discussed here in relation to their affective component. Margraf (1990) reviewed six studies examining the occurrence of panic attacks that gave the time of day at which the panic attacks occurred (Taylor, Sheilch, Agras, Roth, Margraf, Ehlers, Maddock, and Gossard, 1986; White and Baker, 1986; Margraf, Taylor, Ehlers, Roth, and Agras; 1987; Margraf, Taylor, Ehlers, Roth, and Agras; in preparation; Shear, Polan, Harshfield, Pickering, Mann, Frances, and James; unpublished manuscript). Panic attacks showed a distinct circadian pattern, with the highest percent of attacks occurring in the late morning hours. When type of attack was examined, it was found that both situational and spontaneous attacks showed basically the same circadian curve, with both peaks occurring in the late morning (Margraf, 1990).

Two studies have examined self-reports of "stress" across the day. A study by Watts, Cox, and Robson (1983)

looked at reports of "negative hedonic tone" (feelings of tenseness, worry, and discomfort). Subjects made self reports of their feelings at five points during the day, ranging from 9:00 a.m. to 5:00 p.m. This study found no evidence for a circadian variation in self reports of stress across the day. However, Caminada and DeBruijn (1992) found that self reports of "tense arousal" varied across the day, with the highest level occurring at 9:00 a.m. Furthermore, reports of energetic arousal, pleasantness, and elation all were significantly reduced at 9:00 a.m. as compared with the rest of the day (Caminada and DeBruijn, 1992). Clark, Watson, and Leeka (1989) examined self reports of mood every three hours over a one-week period. They found that positive affect was low upon awaking, but increased throughout the morning, stayed level throughout the day, and then began to drop around 9:00 p.m. Negative affect did not reveal any variation across time. Thus, it is unclear from the research whether feelings of "stress" vary across the time of day. However, the clinical findings that panic attacks occur more frequently during the morning hours suggest that people may be the most vulnerable to stress at this time.

<u>Circadian Variation of Behavioral Parameters</u>

Studies of shift work, where people work at different

portions of the day, provide evidence regarding the variance of performance across the day. Monk and Folkard (1992) review some of the effects of shift work on performance. They review several studies, which together, provide a complete picture of how performance varies across the circadian period. Folkard and Monk (1992) categorize these studies into studies measuring speed or accuracy of the task (Browne, 1949; Wojtczak-Jaroszowa and Pawlowska-Skyba, 1967; Bjerner and Swensson, 1953) and those examining attentional processes (Hildebrandt, Rohmert, and Rutenfranz, 1974; Folkard, Monk, and Lobban, 1978). These studies reveal a consistent pattern of performance being the lowest during the night hours, as well as a decrease in performance following lunchtime (Monk and Folkard, 1992). An example of this "real life" look at circadian performance is the study by Folkard and colleagues (1978) which examined the occurrence of accidents during the different shifts of hospital nurses. They observed that the peaks in accidents occurred at midnight and 5:00 a.m. This observation lends support to the idea that performance is lower during the night hours.

Circadian Variation of Clinical Cardiovascular Events

The physiological, psychological, and behavioral processes exhibiting circadian variation may have

consequences for cardiovascular disease. Specifically, there is evidence that clinical cardiovascular events also exhibit circadian rhythms. Myocardial infarction (MI) was first observed to occur with an uneven distribution throughout the day and a disproportionate number of events occurring during the morning hours (Master, 1960, Pell and D'Alonzo, 1963; Thompson, Blandford, Sutton, and Marchant, 1985). A criticism of these findings involves the timing of the reports of myocardial infarction, which were assessed via subjective reports of pain. Many of these events may actually occur during the nighttime, but the patient might only become aware of their symptoms upon awakening, thus accounting for the morning peak. However, later studies employed plasma creatine kinase MB testing to verify the presence of myocardial infarction; this allows for reasonably accurate estimations of the time of onset for myocardial infarction (Roberts, Gowda, Ludbrook, and Sobel, 1975). Muller and colleagues (1985) used this technique and were able to determine time of onset in 703 of 817 MI patients. The time of onset for MI peaked from 5:00 a.m. to 2:00 p.m. and included a secondary peak in the early evening (7:00-9:00 p.m.). The number of MI's from 6:00 a.m. to 12:00 p.m. was 1.43 times the average of the other time periods (Muller, Stone, Turi, Rutherford, Czeisler, Parker, Poole, Passamini, Roberts, Robertson, Sobel, Willerson,

Braunwald, and the MILIS Study Group, 1985). These results have been replicated by other studies that also show the morning peak in the incidence of myocardial infarction (Willich, Linderer, Wegscheider, Schroeder, and the ISAM Study Group, 1988; Goldberg, Brady, Chen, Gore, Flessas, Greenberg, Thedosiou, Dalen, and Muller, 1989).

Muller and colleagues (1987) observed that the circadian variation of sudden cardiac death corresponds to that found for MI, with the largest peak observed from 10:00 a.m. to 11:00 a.m. and a smaller peak from 5:00 p.m. to 6:00 p.m. (Muller, Ludmer, Willich, Tofler, Aylmer, Klangos, and Stone, 1987). Using data from the Framingham Heart Study, Willich and colleagues (1987) also found significantly more sudden cardiac death during the morning hours (6:00 a.m. to 12:00 p.m.). These data suggest that the risk of sudden cardiac death is 70% greater from 7:00 a.m. to 9:00 a.m. and provides further evidence for an increased risk of cardiovascular events in the morning hours.

Myocardial ischemia occurs when the heart fails to get enough oxygen to function properly. Ischemia can be measured non-invasively using an ambulatory electrocardiogram monitor, thus allowing monitoring of ischemia over time. Ambulatory monitoring of hospital patients reveals that episodes of ischemia occur most frequently during the morning hours, with a concurrent rise in heart rate

(Quyyumi, Mockus, Wright, and Fox, 1985). Similarly, Mulcahy and colleagues showed a circadian variation for ischemic episodes, with a primary peak during the morning and a secondary peak during the evening (Mulcahy, Keegan, Cunningham, Quyyumi, Crean, Park, Wright, and Fox, 1988). Rocco and colleagues (1987) also found a morning peak in ischemia with 39% of the episodes and 46% of total ischemic time occurring during the morning. Furthermore, when wake time was accounted for, it was found that peak ischemic activity occurred in the first two hours following waking. This study also suggests that the threshold at which ischemia can occur may be lower during the morning hours. Thus, when heart rate reaches a certain level during the morning, ischemia is more likely to occur (due to increased demand) than for the same heart rate during the evening hours (Rocco, Barry, Campbell, Nabel, Cook, Goldman, and Selwyn, 1987). Krantz and colleagues also showed that ischemic activity was the greatest within the first six hours of awakening. The number of episodes showed a morning and evening peak in activity. Using a hierarchical regression approach, this study found that time of day predicted a significant amount of variance beyond that accounted for by physical activity. This suggests that endogenous factors contribute to the circadian variation of myocardial ischemia. However, ischemia did not show a

circadian pattern at low levels of activity. This suggests that while the threshold for the development of ischemia has an endogenous circadian variation, the exogenous factor of physical activity contributes to the circadian variation typically found (Krantz, Gabbay, Klein, Nebel, Hedges, Gottdiener, and Rozanski, in preparation).

Finally, the incidence of stroke is also not random throughout the day. Three kinds of stroke have been examined and all show a circadian variation with a peak between 10:00 a.m. and 12:00 p.m. Furthermore, one type of stroke showed an evening peak as well, matching rhythms found for myocardial infarction and ischemia (Tsementzis, Gill, Hitchcock, Gill, and Beevers, 1985). (For reviews of cardiovascular disease and circadian rhythms see Rocco, Nabel, and Selwyn, 1987; Muller, Tofler, and Stone, 1989; and Quyyumi, 1990)

Drug studies provide an interesting perspective regarding the circadian variation of sympathetic activity and its relation to the circadian variation of cardiovascular events. Circadian studies of clinical cardiovascular events have noted that for subsamples of subjects on beta-blockers the morning peak in myocardial infarction was not found (Muller et al., 1985). Similar findings have been shown for ischemia, with beta-blockers eliminated the morning peak (Mulcahy, Keegan, Cunningham,

Quyyumi, Crean, Park, Wright, and Fox, 1980). Corresponding to these findings, other research found that the morning surge in heart rate was attenuated with beta-blocker use (Lambert, Coy, Imperi, and Pepine, 1989). On the other hand, Gould and Raftery (1991) review the literature and suggest that alpha-adrenoceptor blockers stop the morning surge in blood pressure, whereas beta-blockers appear to have little effect. This would suggest that alpha-adrenoceptor activity leads to the morning increase in blood pressure (Gould and Raftery, 1991). Calcium-channel blockers have not been found to affect circadian variations of ischemia (Mulcahy, et al., 1980). Similarly, aspirin does not appear to reduce the morning peak in myocardial infarction (Willich et al., 1989).

Circadian Variation of Responses to Specific Stimuli

While physiological, behavioral, and psychological parameters show circadian variation under standard conditions, the studies discussed so far involve measures taken during daily life or under restricted laboratory conditions. These types of studies are both valuable in determining circadian variations in general, but do not examine particular stimuli. Another area of research involves examining the effects of responses to specific stimuli at different times of the day. One such stimulus

used is exercise. Physiological response to exercise shows very little circadian variation. In studies of coronary artery disease (CAD) patients undergoing exercise testing at different times of the day, there are few consistent findings. It appears that the heart rate at which ischemia occurs or the amount of exercise required to trigger ischemia does not vary significantly across the day (Handler and Sowton, 1985; Opasich, Falcone, Cabelli, Assandri, Larovere, Riccardi, Tremarin, Ardissino, and Specchia, 1987; Khurmi and Raftery, 1988). Cohen (1980) gave subjects maximal exercise tests at seven time points across a 24-hour period. While resting heart rate showed a circadian variation, as expected, the heart rate response to maximal exercise exhibited no discernible circadian variation. O'Connor and Davis (1992) also found no circadian variation of heart rate or blood pressure in response to exercise. However, other research has found that exercise in combination with heat stress produces greater heart rate responses during the morning (6:00 a.m. - 12:00 p.m.) (Zahorska-Markiewicz, Debowski, Spioch, Zejda, Sikora, and Markiewicz, 1989).

Mood changes in response to exercise also have been examined regarding their relationship to time of day. Whereas state anxiety and state anger were reduced following exercise, this reduction was independent of the time of day.

These results suggest that psychological changes in response to exercise do not exhibit a circadian variation (O'Connor and Davis, 1992). (See Reilly (1990) for a review of the literature concerning exercise and circadian rhythms.)

The effects of stress on performance across the day have also been examined. Loeb, Holding, and Baker (1982) looked at the effects of noise on performance of a math task across the day. An AM session beginning at 8:00 a.m. or 9:00 a.m. and a PM session beginning in the late afternoon were examined. For male subjects noise interfered with performance during the AM whereas noise in the PM tended (non-significantly) to increase their performance. These results were not found for women. The authors suggest that noise presents a challenge which men have trouble dealing with during periods of low arousal (AM) but noise may help performance when arousal is high (PM) (Loeb, Holding, and Baker, 1982). Thus, stress may interact with the circadian curve of arousal to produce varying effects on performance depending upon the time of day and the type of task.

Circadian Type: The Dimension of Morningness-Eveningness

While the circadian variation of a whole host of psychological, physiological, and behavioral factors has been examined, individual differences have been frequently overlooked as possible contributors to circadian variations.

However, the dimension of Morningness-Eveningness has particular relevance to the study of circadian rhythms. Kleitman (1939) described the concept of "Morning" and "Evening" types as well as a third type called "Intermediate". Oquist (1970) developed a questionnaire in Swedish to differentiate Morning and Evening people. This was followed by the development of the English version of the Morningness-Eveningness Questionnaire (MEQ) by Horne and Ostberg (1976). This 22-item English version was then given to 150 subjects. Three items were found not to discriminate between circadian types and were consequently dropped. The final questionnaire contains 19 items and is designed to assess individuals' preferences for what time of day they prefer to engage in a variety of activities, such as sleeping, waking, eating, exercise, and thinking, and when they feel the "best" in general. The scale produces a continuous score ranging from 16 - 86 with higher scores representing greater degrees of Morningness. This score can further be divided into one of five categories: Definitely Morning Type, Moderately Morning Type, Neither Type, Moderately Evening Type, and Definitely Evening Type. However, theoretically, the circadian type of individuals falling into the "Neither" type can be very different. These individuals could feel good in both the morning and the evening, feel good in the afternoon, feel good all the

time, or feel bad all of the time. Thus, this category may not be particularly useful in defining an individual's circadian type.

Horne and Ostberg validated the MEQ using 48 subjects who took their temperature at half-hour intervals throughout the day for three weeks. The peak temperature for Morning subjects occurred significantly earlier in the day compared to Evening subjects (7:32 p.m. vs. 8:40 p.m.), while the intermediate type fell between these two times. This study also found that behavioral measures also differed between the two circadian types, with bedtime and awaketime occurring earlier for the Morning subjects. Posey and Ford (1981) gave the MEQ to 259 college students. They found that the MEQ had a normal distribution (with slight negative skewness). Scores on the MEQ were not different depending upon the time of administration, and no gender differences were observed. The coefficient alpha of reliability was r =.89 (Kuker-Richardson formula number 20), thus showing acceptable reliability for this instrument. Similarly, Neubauer (1991) found a coefficient alpha of .86, and Smith, Reilly, and Midkiff found a coefficient alpha of .82.

While the MEQ is the most commonly used scale to detect circadian preferences, other scales have also been used. Although the Diurnal Type Scale (DTS) by Torsvall and Akerstedt (1980) also measures circadian type, this scale

was developed using shift workers and therefore is not necessarily generalizable to people on a "normal" schedule. Folkard, Monk, and Lobban (1979) also used a shift work sample when developing the Circadian Type Questionnaire (CTQ). Greenwood (1991) compared the DTS with the MEQ and CTQ and concluded that the DTS should be used with caution since it correlates only moderately with the other two circadian scales. Smith, Reilly, and Midkiff (1989) also compared all three scales using 501 subjects. These researchers factor analyzed each scale and computed alpha coefficients to estimate the level of internal consistency. Based on their analyses, they concluded that none of the questionnaires were ideal. They conclude that the DTS is only marginally adequate regarding interitem reliability and the CTQ has "poor interitem psychometric properties". Regarding the MEQ specifically, these researchers found this scale to be adequate but believe it may be too long (Smith, Reilly, and Midkiff, 1989). However, a shorter version of the MEQ is now available (rMEQ) (Adan and Almirall, 1991). Although the MEQ is subject to some criticisms it still appears to be the best choice. This is particularly true since it is used in so many circadian studies and use of the MEQ makes comparisons between studies less complicated.

Potential differences between Morning and Evening people have been examined for several parameters. Just as

circadian rhythms have been examined for psychological, behavioral, and physiological variations, so too, has the dimension of Morningness-Eveningness. Circadian type may interact with time of day to produce different patterns of circadian variation for different individuals.

Physiological Parameters and Circadian Type

How a person's circadian type affects their physiological rhythms has been examined in a number of ways. As discussed earlier, Horne and Ostberg (1976) showed that body temperature curves vary with Morningness-Eveningness, with Morning subjects peaking earlier in the day. This finding has been replicated in a number of studies (e.g., Horne and Ostberg, 1977; Neubauer, 1992). Patkai (1971a) compared ten "Morning" workers and nine "Evening" workers; this designation was based on the time these people normally preferred to do their work. Catecholamine excretion was measured as an indication of arousal, at two points during the day. Results revealed that the "Evening" workers excreted more epinephrine during the evening as compare to the morning period. On the other hand, "Morning" workers tended to excrete more epinephrine during the morning period. No differences were found for norepinephrine between "Morning" and "Evening" types. Another study by Patkai (1971b) looked at catecholamine excretion at several

time points across the day. "Morning" workers excreted the most epinephrine during the first time period of the morning and then decreased throughout the day. "Evening" workers, on the other hand, excreted epinephrine throughout the day. Again, there was no interaction between circadian type and time of day found for norepinephrine.

Cortisol, another endocrine measure associated with arousal, has also been examined for differences between circadian types. Bailey and Heitkemper (1991) compared 10 Morning and 10 Evening subjects based on the MEQ and preferences for activity and alertness. Salivary cortisol samples were collected every 20 minutes for two hours after waking. Results showed a trend for Morning subjects to have higher values earlier and Evening subjects had higher values later. However, these group differences were not significant. These preliminary results suggest that there may be differences for cortisol depending upon circadian type and time of day. Furthermore, because cortisol was examined only during the morning, future studies should examine cortisol across the day and how its circadian variation interacts with circadian type.

Other physiological parameters that have been assessed regarding their relationship to circadian type include electrophysiological variables. Zani (1986) examined Morningness-Eveningness and amplitude of evoked potentials

in response to a visual stimulus. Seven Morning subjects and six Evening subjects were brought into the laboratory on two different days. One session took place at 9:00-10:00 a.m. and the other session at 18:00-19:00 p.m. Results suggest that there are hemispheric asymmetries depending on circadian type and time of day, with higher amplitudes occurring in the Morning subjects during the morning session, while Evening subjects produced higher amplitudes during the evening session. Furthermore the left hemisphere appears to be more active during a subject's preferred time of activity (e.g. Morning subjects have greater left hemisphere ERP amplitudes during the morning). Geisler and Polich (1992), using an auditory stimulus, showed that the P300 event related potential (ERP) amplitude interacted with time of day, circadian type, and food intake. When no food had been eaten beforehand, Morning subjects showed higher amplitudes in the morning and Evening subjects showed higher amplitudes during the evening. The consumption of food appears to interfere with this interaction. These studies suggest that the circadian variation of electrophysiological measures of attention (ERP) interact with the circadian type of the individual.

Skin conductance levels have also been used as an index of arousal in psychophysiological studies (Venables and Martin, 1967). Wilson (1990) had 101 subjects measure their

own skin conductance every hour throughout the day using an ambulatory palmar conductance device. Morning subjects peaked around 2:00 p.m. to 3:00 p.m. whereas Evening subjects peaked later, at about 5:00 p.m. to 6:00 p.m.. The authors also report that Morning subjects show higher levels during the morning and Evening subjects show higher levels during the evening hours. However, it is unclear whether this difference was significant (Wilson, 1990).

Taillard and colleagues (1990) compared the peak time of heart rate for Morning and Evening subjects. With continuous monitoring, they found that Morning subjects peaked at 1:30 p.m. whereas Evening subjects peaked at 5:30 p.m. These results are similar to those reported for skin conductance levels by Wilson (1990).

Psychological Parameters and Circadian Type

Research reviewed previously has shown that circadian type interacts with time of day to produce differing physiological rhythms. Do psychological variables also show a similar interaction with circadian type? The answer appears to be yes. Watts, Cox, and Robson (1983), using the Stress Arousal Check List, observed that Morning subjects reported the highest arousal at 9:00 a.m. and 11:00 a.m. and the lowest at 5:00 p.m. Evening subjects, on the other hand, reported low arousal at 9:00 a.m. and higher arousal

throughout the rest of the day. Other studies have also shown that Morning subjects report greater arousal during the morning and Evening subjects report more arousal in the evening (Mecacci, Scaglione, and Vitrano, 1991). Clodore, Foret, and Benoit (1986) also found that Morning subjects reported greater alertness upon arising in the morning than did the Evening subjects. Further research shows that the crossover, where Morning subjects become less alert and Evening subjects become more alert occurs sometime between 4:00 p.m. and 8:00 p.m. (Vidacek, Kaliterna, Radosevic-Vidacek, and Folkard 1988). When Clark, Watson, and Leeka (1989) examined subjects who were either Morning or Evening, they found that subject type interacted with time of day to produce different levels of positive affect. This effect, however, was due to the Morning subjects reporting higher positive affect during the morning as compared to the Evening subjects. Evening subjects did not, however, report greater levels than the Morning subjects during the evening hours.

Self-reports of stress also vary throughout the day depending upon an individual's circadian type. Mecacci et al. found that self reports of stress decrease from morning to evening in the Morning subjects. Evening subjects show an opposing pattern, with reports of stress increasing across the day.

Behavioral Parameters and Circadian Type

The most obvious behavioral factor that might vary between Morning and Evening subjects is the sleep-wake cycle, since this is a behavior that is addressed in the questionnaire. A number of studies show that Morning subjects wake earlier and go to bed earlier than do Evening subjects (e.g., Horne and Ostberg, 1976; Horne and Ostberg, 1977; Torsvall and Akerstedt, 1980; Larsen, 1985; Neubauer, 1992). These differences in sleep-wake cycles suggest that the MEQ is a valid measure of circadian type preferences, since one would expect there to be differences in sleep patterns between Morning and Evening subjects.

Performance also varies across time of day depending upon circadian type and the type of task. Patkai (1971b) examined several types of tasks over the day and between Morning and Evening workers. A reaction time test showed that Morning subjects responded with similar speeds throughout the day, while Evening subjects became faster at responding as the day went on. Patkai also used a math task and the Stroop color word task (Thurstone and Mellinger, 1953) and found that performance increased as the day went on in both types of subjects. However, since all of the test sessions were on the same day, practice effects could account for the increased performance throughout the day, thus camouflaging any circadian type effects that might have

occurred (Patkai, 1971b). However, in the math test, Evening subjects did perform significantly better during the evening hours than they did in the morning. Horne, Brass, and Pettitt had subjects perform a production line task where subjects had to detect defective items. Unlike the Patkai study, Horne and colleagues randomized sessions across five days (three sessions each day). As predicted, they found that Morning subjects performed the task better during the morning hours and Evening subjects performed better in the evening. Similar interactions were found by Monk and Leng (1986) for a cognitive task involving verbal reasoning; Morning subjects performed better during the morning while Evening subjects performed better during the evening. Adan (1991) found no differences between Morning and Evening subjects for a verbal memory task, but found differences on a reaction time task with Evening subjects slower during the 11:00 a.m. session. Thus, while some tasks show the predicted interaction, not all do. However, it is very important, particularly in the area of performance tasks to randomize or counterbalance the session times across different days. Otherwise, practice effects limit the conclusions that can be drawn from the data.

What Determines Circadian Type?

What makes a person a Morning person or an Evening

person? Are people born with particular circadian preferences or do they entrain or adapt to the schedules that are placed upon them? Based on the available research, it is not possible to offer clear answers to these questions. Although there appear to be few gender differences for Morningness-Eveningness (Wilson, 1990; Neubauer, 1992), people's preference for morning activity increases with age, and that the MEQ is positively correlated with age indicating greater morningness (Mecacci, Zani, Rocchetti, and Lucioli, 1986; Wilson, 1990; Drennan, Klauber, Kripke, and Goyette, 1991; Ishihara, Miyake, Miyasita, and Miyata, 1991). Thus, some aspect of the aging process appears to contribute to the development of greater morning tendencies.

A number of personality variables also appear to vary with circadian type. One of the most widely studied has been the concept of Introversion/Extroversion (Kerkhof, 1985). A number of studies show that Morning subjects tend to be more Introverted and Evening subjects tend to be more Extroverted (Folkard, Monk, and Lobban, 1979; Larsen, 1985). Still other studies find only trends or no relationship (Horne and Ostberg, 1977; Mecacci et al., 1986). (See Kerkhof (1985) for a review of Introversion/Extraversion and its relationship to circadian type). Other studies have found Evening subjects to be more neurotic (Torsvall et al.,

1980; Neubauer, 1992), and to score higher on psychotocism (Mecacci et al., 1986) and anxiety (Matthews, 1988). Drennan and colleagues (1991) observed that patients with depression displayed greater levels of Eveningness than did the control subjects, and Matthews (1988) found male Evening subjects to show higher anxiety and psychotocism. Matthews suggests that these mental health problems may interfere with the processing of zeitgebers (time cues) and may result in a shift toward Eveningness. Corresponding to these personality findings, researchers have also found Evening subjects to evidence greater substance use (e.g. caffeine, nicotine, and alcohol) (Ishihara, Miyasita, Inugami, Fukuda, Yamazaki, and Miyata, 1985). Ishihara and colleagues suggest that using substances such as caffeine may cause a phase shift in the individual's circadian rhythm causing them to be show greater levels of Eveningness.

Cultural differences may also exist regarding Morningness-Eveningness. The best example of this is a study by Aguiar, Da Silva, and Marques (1991) which examined a Brazilian Amazon rural community and a nearby urban area with people of similar genetic makeup. The rural population consisted of 95% morning type individuals, whereas the urban area nearly 30% intermediate types. Thus, culture, as in that of a rural tribe or an urban area, appears to affect circadian type when genotype is held constant. Note,

however, that both groups are still more morning-oriented than the typical American sample.

Work schedule also may affect Morningness. Adan (1992) found that people who work in the morning exhibit greater degrees of Morningness. Thus, people may be able to adapt to a morning schedule and proceed to show greater levels of Morningness, as was suggested by the rural versus urban samples in the Amazon. On the other hand, people who prefer the morning may self select schedules that emphasize the morning hours.

Finally, attentional processes may vary between Morning and Evening subjects depending upon the time of day. The electrophysiological data described earlier suggest that Morning and Evening subjects respond differently to stimuli at different times of the day, with Morning subjects exhibiting higher ERP amplitudes during the morning and Evening subjects showing higher amplitudes during the evening. Therefore, the way an individual processes information may also vary as demonstrated by these results. As will be discussed later, this has implications for reactivity to stress. Lazarus (1966) was the first to emphasize the importance of perception or appraisal of a stressor in the stress response. If Morning and Evening subjects perceive events or stressors differently across the day this could affect their psychological and physiological

responses. Therefore, attentional processes may account for some of the differences found between Morning and Evening subjects.

The research discussed above shows that several variables correlate with Morningness-Eveningness. These results suggest that a variety of genetic, cultural, behavioral, and psychological factors may coalesce to contribute to an individual's circadian type.

Model of circadian phase

Although measured on a continuum, Morningness-Eveningness can, for the purposes of this study, be thought of as a typology. Morning and Evening subjects are defined as two groups distinctive of each other based on a model of physiological circadian phases. This model suggests that Morning subjects are phase advanced in their circadian variations whereas Evening subjects are phase delayed (See Figure 1). While phase shifts occur in this model, amplitude of the circadian rhythm is believed to be the same for both types of subjects. The majority of the population falls into the intermediate range, with a circadian phase falling between the Morning and Evening types. As shown in the model, at certain times of the day Morning and Evening subjects may not exhibit differences on a specific variable (point B on the graph). However, before and after this

crossover point occurs (points A and C on the graph) differences between the two circadian types may be observed. A variety of studies have observed this crossover phenomena and have found differences before and after a specific time point, usually in the afternoon. These phase differences have been observed for physiological (Horne and Ostberg, 1976; Wilson, 1990), psychological (Caminada and De Bruijn, 1992; Watts, Cox, and Robson, 1983), and behavioral parameters (Horne and Ostberg, 1977; Monk and Leng, 1986; Horne, Brass, and Pettitt, 1980; Adan, 1991) across circadian type.

Are these differences in phase endogenously driven or do external factors such as activity contribute to the phase differences observed? The answer may be both endogenous and exogenous factors influence phase differences between Morning and Evening subjects. Body temperature, a primarily endogenous rhythm shows phase differences between Morning and Evening people (e.g. Horne and Ostberg, 1976). Whereas, skin conductance, a physiological variable that is influenced by activity, also shows phase differences. Thus, it can not be said that Morning and Evening subjects differ primarily due to either endogenous or exogenous factors, but to both. Similarly, studies which define Morning and Evening subjects based on external factors such as work schedules (e.g. Patkai, 1971a 1971b) find phase differences

similar to those studies, described above, which define Morning and Evening subjects based on the individual's preferences. Therefore, whether circadian type is defined by activity or by preference circadian phase shifts are observed which correspond to the model of circadian phase described above.

The model of circadian phase presented in this study will be based on preferences assessed using the Morningness/Eveningness Questionnaire. This questionnaire categorizes people based solely on their self-reports of when they prefer to do a variety of activities as well as when they feel their best. This study is not designed to assess underlying physiological differences that may exist between Morning and Evening subjects or to discover what underlying neural mechanisms may contribute to the preferences observed. Furthermore, the activity schedules of Morning and Evening subjects will not be assessed and what role these schedules play in the development of peoples' circadian preferences. These issues will be left for future research. Although activity schedule and neurological differences may interact to produce time preferences, only these preferences will be assessed here.

The Effects of Stress

The literature discussed above suggests that a variety

of physiological, psychological, and behavioral parameters vary throughout the day. Do people's response to stress also vary throughout the day? Furthermore, does circadian type interact with time of day to produce a different stress response at different times? Stress can be defined as "the process through which organisms respond to internal or external environment that are perceived as threatening or dangerous" (Lester, Nebel, and Baum, 1993). Stress has long been thought to be a biological response (Cannon, 1935; Selye, 1976), consisting of an activation of the sympathetic nervous system that leads to release of catecholamines and corticosteroids. These changes can contribute to cardiovascular responses such as increases in heart rate and blood pressure. Stress, however, is not strictly a physiological response, but has psychological components as well. More recently, the importance of cognitive appraisal and its role in the stress process, has been realized (Lazarus, 1966). Consequently, researchers have become aware of the importance of measuring stress using a multilevel approach (Baum, Grunberg, and Singer, 1982). Therefore, when examining the effects of stress, researchers should employ physiological, psychological, and behavioral measures. Physiological measures of the stress response can include heart rate, blood pressure, and endocrinological measures. Psychological factors are frequently measured via

self-report of affective changes. Finally, behavioral changes to stress can be measured by looking at performance decrements. Easterbrook (1959) suggests that how people perceive their environment changes with the level of stress, and that after a certain point as stress gets greater, the ability to attend to environmental cues decreases. This interference with attention then leads to either decreases or increases in performance depending upon where in the arousal curve the task is taking place. At low levels of arousal an emotional response can increase performance by increasing cue utilization. But after a certain level, the stress response begins to interfere with cue utilization and leads to decrements in performance (Easterbrook, 1959; Yerkes and Dodson, 1908).

The stress response can occur not only while a stressor is present; research has shown that effects can be observed after the stressor ceases. Aftereffects can be defined as "consequences that are experienced after exposure to a stressor has terminated..." (Gatchel, Baum, and Krantz, 1989). Glass and Singer (1972) examined performance following a noise stressor. Although consistent effects were not observed during the noise stressor, aftereffects were observed following the completion of the noise period. Subjects exposed to noise were found to be less tolerant of a frustrating task and to have less concentration on a

proofreading task (Glass and Singer, 1972). This research demonstrates the importance of examining responses after the original stressor has ended, particularly on measures of performance.

Reactivity to Stress

As was defined earlier, psychophysiological reactivity to stress represents a change from baseline of an individual's physiological responses to a stressor or challenge (Krantz and Manuck, 1984). Changes is psychological states in response to stress can also be examined in reactivity research. Reactivity to stress can be operationalized by subtracting resting levels of cardiovascular, endocrine, or self-reports of affect from the level obtained in response to the stressor (delta score). For analyses of the reliability of delta scores see Llabre and colleagues (Llabre, Spitzer, Saab, Ironson, and Schneiderman, 1991). Reactivity has been examined in a wide range of laboratory studies looking at the effects of different stressors on physiological and psychological measures.

Reactivity has been widely studied because of its possible relationship with the development atherosclerosis and coronary artery disease. Animal and human studies suggest that high degrees of reactivity may increase risk

for the development of coronary artery disease (Krantz and Manuck, 1984). Animal studies have shown that male monkeys who are high heart rate reactors (under threat of capture) developed significantly greater amounts of coronary artery atherosclerosis than monkeys who were low heart rate reactors (Manuck, Kaplan, & Clarkson, 1983). Similar findings were found in a follow-up study using female monkeys (Manuck, Kaplan, Adams, and Clarkson, 1989).

One mechanism by which these changes may occur is put forth by Beere and colleagues (1984). These researchers observed that in monkeys who had been surgically altered to have lower heart rates, levels of atherosclerosis were also lower six months later when compared to monkeys who did not have surgically lowered heart rates. Their research suggests that reactivity may lead to the development of CAD through increased hemodynamic responses damaging the endothelium of the coronary arteries. They suggest that increases in heart rate may lead to the development of atherosclerosis in those parts of the arteries undergoing the greatest changes in flow (Beere, Glagov, and Zarins, 1984).

Human studies also suggest a relationship between greater levels of reactivity and the development of coronary artery disease (CAD). Keys and colleagues (1971) found that diastolic blood pressure responses were related to the

development of coronary disease twenty-three years later.

While reactivity can influence development of coronary artery atherosclerosis, it may also influence the triggering of acute cardiovascular events. For example, reactivity and cardiovascular levels have been related to the levels of myocardial ischemia found to mental stress in the laboratory (Krantz, Helmers, Bairey, Nebel, Hedges, and Rozanski, 1991). In this study, those CAD patients with the severest ischemia also had the greatest levels and increases in systolic blood pressure.

Circadian Variation of Psychophysiological Reactivity

One study has examined how physiological and psychological responses to stress vary across the day (Levy, unpublished thesis, 1988). Although this study did not look at reactivity per se, it did examine cardiovascular levels obtained from eleven subjects in response to the Stroop color work task at 9:00 a.m. and 9:00 p.m. This study found no variation across time in the heart rate, systolic blood pressure, diastolic blood pressure, other cardiovascular levels, and reports of disturbance reached during the Stroop task. However, the subjects used in this study were coronary artery disease patients on medication during the testing sessions. As described earlier, it has been noted in the literature that certain types of cardiovascular

medications (e.g., beta blockers) can alter the circadian variation found for cardiovascular factors and events, and possibly for reactivity as well (Mulcahy, et al., 1980; Muller, et al., 1985; Lambert, et al., 1989). Thus, the use of subjects on medications confounds the goal of this study and may have dampened circadian variation of the cardiovascular responses.

Two other studies have examined variation of reactivity with time. A study done in our laboratory with nineteen healthy subjects examined reactivity at two different times during the day. Using a within-subject design, subjects came to the laboratory for two counterbalanced sessions about three weeks apart, one at 7:30 a.m. and the other at 12:30 p.m. Subjects performed a computerized math/Stroop task and a physical handgrip task. The math/Stroop task involved alternating 2.5 minutes of math (addition and subtraction) with 2.5 minutes of the Stroop color word task, for a total of ten minutes. The handgrip task involved gripping a hand-held dynamometer for 1.5 minutes at 30% of the subjects maximum handgrip. Heart rate, systolic blood pressure, diastolic blood pressure, and rate pressure product (HR x SBP = a measure of cardiac demand) responses were examined. Self reports of "interest", "anger/irritation", and "anxiety/tenseness" were also measured. While the tasks increased physiological and

psychological measures of stress, these measures did not appear to vary across the AM-PM sessions for either levels or change scores. Thus, this study did not support the idea of a circadian variation of psychophysiological reactivity (Nebel et al., 1994).

However, when circadian type was examined using the MEQ, significant interactions were found such that individual differences in Morningness-Eveningness interacted with the time of day to produce varying responses to stress. A median split on the continuous MEQ score divided subjects into ten Morning and nine Evening subjects. However, this median split may have shortcomings due to the number of intermediate subjects in this sample. Ideally, only "true" Morning and Evening subjects should be used. ANOVAs for cardiovascular levels revealed marginally significant interactions (AM/PM x MEQ x Task) for SBP and rate pressure product (RPP) ($p<.09$ and $p<.06$) (See Figure 2). Rate pressure product (heart rate x systolic blood pressure) is used as a marker of myocardial demand. Cardiovascular change scores showed a significant AM/PM x MEQ interaction for SBP and RPP ($p<.03$ and $p<.03$) (See Figure 3). Self-reports of stress revealed a marginal AM/PM x MEQ interaction for "angry/irritated" ($p<.06$). All of these analyses indicated that Morning subjects evidenced increased responses (cardiovascular and psychological) during the AM

session while Evening subjects responded more during the PM session.

Similar to the study just described, another study conducted by our research group used eleven coronary artery disease patients in a within-subjects design, with the morning session occurring at approximately 8:00 a.m. and the afternoon session occurring at approximately 1:00 p.m. These two sessions occurred about four months apart. Subjects were administered a serial subtraction math task and a speech task regarding personal faults (session 1) or an embarrassing or stressful event (session 2). Both of these stressors significantly increased cardiovascular levels (HR, SBP, DBP, and RPP) and self reports of "tense", "anger", "anxious", and "arousal". Only two measures, HR and RPP change scores, showed time differences. However, these differences were not in the predicted direction. Instead, these measures were found to be higher during the PM session. The majority of cardiovascular and psychological levels and change scores showed no main effects for time of day (Nebel et al., 1994).

In this study, potential interactions of time of day with Morningness/Eveningness were again examined. Seven true Mornings (as classified by the MEQ) and the other four subjects were compared in this CAD population. Results showed similar interactions between AM/PM session and MEQ.

MANOVAs on cardiovascular levels revealed significant AM/PM x MEQ interactions for all of the cardiovascular levels: SBP ($p<.05$), DBP ($p<.04$), HR ($p<.05$) and RPP ($p<.01$) (See Figure 4). Change score analyses showed significant AM/PM x MEQ interactions for DBP and RPP ($p<.006$ and $p<.05$) (See Figure 5). Self reports of stress also revealed significant AM/PM x MEQ interactions for "arousal" ($p<.05$), and marginally significant interactions for "anxiety" and "anger" ($p<.06$ and $p<.06$). Again, in general, these results showed the Morning subjects have larger cardiovascular and psychological responses during the AM session while Evening subjects demonstrated larger responses in the PM session.

In light of these results, it is worth reconsidering findings reported earlier involving the morning and evening peaks for myocardial infarction and myocardial ischemia (Krantz, Gabbay, Klein, Nebel, Hedges, Gottdiener, & Rozanski, unpublished manuscript). It is highly possible that these two peaks may be explained by two separate populations of Morning types and Evening types, such that Morning subjects have a morning peak in ischemia whereas Evening subjects peak later. Because ischemia can be caused by the increased myocardial demand associated with reactivity, this would lend further support to the idea that reactivity may vary within these two populations. Preliminary field data from the our research group suggests

that the occurrence of myocardial ischemia varies with circadian type. Subjects wore an ambulatory holter monitor to measure the patient's 48-hour electrocardiogram during daily life. An ischemic episode was defined as an ST-segment depression of one mm or greater. Those subjects with a MEQ score available (N=11), were classified as Morning or Non-Morning subjects. Chi-square analyses for both the frequency of ischemic events as well as the total duration of ischemia suggest that the distribution of these variables across time of day varies with circadian type. Morning subjects show greater frequency and duration of ischemia during the first twelve hours of the day (midnight - noon), whereas Non-Morning subjects had a greater number of events and total duration during the second twelve hours of the day (noon - midnight) (p's<.01) (See Tables 1 and 2).

The results of both preliminary reactivity studies reviewed above show consistent interactions between time of day and the circadian type of the subjects. These results are promising, given the low number of subjects in these studies and the large number of intermediate types in the sample, and suggest that Morning subjects respond more to stress during AM sessions while Evening subjects respond more in PM sessions. Because these studies had such large numbers of intermediate types, which may interfere with finding distinct circadian curves depending upon type,

future research should screen specifically for Morning and Evening subjects to maximize potential differences.

The results of these two studies suggest that there may not be a consistent circadian variation in the cardiovascular and psychological responses to stress across individuals. However, these studies may not have been the ideal test of this hypothesis. The timing of the sessions may not have been optimal to detect circadian differences. The start times of approximately 7:30-8:00 a.m. or 12:30-1:00 p.m. were chosen based on the circadian variation of clinical cardiovascular events. The notion in designing these studies was that if clinical events such as myocardial infarction, ischemia, and sudden death all peak in the morning hours and have a relatively low incidence in the early afternoon, reactivity may show a similar pattern. However, the afternoon session of these two studies may have been too close to the AM session for differences in reactivity to be detected. Thus, research needs to examine the effects of stress on reactivity at other time points, preferably a time point later in the afternoon or evening.

In addition, regarding psychological factors, the likert-type scale used to assess changes in affect may have been too insensitive to detect potential differences. Future research should utilize a visual analog scale for greater sensitivity in detecting affective changes.

Potential aftereffects of stress on performance should also be examined in relation to circadian type and time of day. Research has shown that the effects of stress are not always observed during the stressor, but may appear after the stressor has ended (Glass and Singer, 1972). These aftereffects may interact with circadian type and time of day to produce different performance decrements. If Morning subjects are highest in arousal during the Morning hours, as has been suggested by previous research, the additional arousal provided by stress may lead to decreased performance following stress. Research by Yerkes and Dodson (1908) suggests that performance follows an inverted U function, such that arousal increases performance up to a certain point after which arousal becomes so intense it decreases performance. While Morning subjects should have their highest level of performance during the morning session, stress may increase arousal beyond the optimal level associated with performance. Therefore, stress should decrease performance for the Morning subjects during the morning sessions, while increasing performance for the Evening subjects during this time period (by increasing their low levels of arousal at this time).

Future research should also be directed toward understanding the mechanism underlying these circadian effects. If changes in attentional processes vary

throughout the day this may be one potential mechanism by which circadian type exerts itself. Physiological indicators of attention, such as EEG responses, have been shown to vary with circadian type and time of day (Zani, 1986; Geisler and Polich, 1992), as do psychological reports of arousal (e.g. Watts, Cox, and Robson, 1983). Further research should examine these processes using a corresponding behavioral measure of attention, such as changes in performance.

SUMMARY AND HYPOTHESES

The purpose of this study was to extend the findings of the pilot work and to correct possible methodological flaws that have limited interpretations of the findings of prior studies. The hypotheses for this study were based on the circadian variation found for a variety of clinical cardiovascular events, and physiological, psychological, and behavioral parameters, and the circadian variation of cardiovascular reactivity to stress. Furthermore, predictions regarding interactions with circadian type were based on the rationale and the preliminary results just reviewed (Nebel et al., 1994). Certain methodological enhancements and corrections suggested from the pilot data were proposed in order to maximize the likelihood of detecting circadian variation and an effect of circadian

type. These include changes in the timing of the study, screening specifically for Morning and Evening subjects, and adding additional dependent measures of affect and performance.

Hypotheses

1. Responses to stress will show a circadian variation, with responses being greater during the morning hours.
   - A. Cardiovascular responses to stress will be greater during an AM testing session (7:30 a.m.) than a PM session (3:30 p.m.).
   - B. Psychological responses to stress will be greater during an AM session than a PM session.
2. Circadian type will interact with time of session to produce different circadian variations in Morning and and Evening types.
   - A. Morning subjects will show greater cardiovascular responses during the AM session, and Evening subjects will show greater responses during the PM session.
   - B. Morning subjects will show greater psychological responses during the AM session, and Evening subjects will show greater responses during the PM session.

C. Attentional processes will vary according to time of session and circadian type. Morning subjects will have faster reaction times and show greater accuracy on the CPT, a test of sustained attention, during the AM session. Evening subjects will have faster reaction times and greater accuracy during the PM session.

D. Aftereffects of stress on performance will vary with circadian type. Stress will disrupt performance in Morning subjects and facilitate performance in Evening subjects during the AM session. Stress will disrupt performance in the Evening subjects during the PM session and will facilitate performance in the Morning subjects during the PM session.

Experiment

The study consisted of a 2 X 2 X 4 repeated measures design with Morningness-Eveningness as a between-subjects factor and AM-PM session as a within-subject factor. Repeated measures were taken across rest, and three tasks: a computerized Stroop task, the Continuous Performance Test, and a physical handgrip task. Dependent measures are systolic blood pressure, diastolic blood pressure, heart rate, rate pressure product (heart rate x systolic blood

pressure), and self-reported levels of stress, as well as performance measures provided by the Stroop, proofreading, and the CPT.

PROCEDURE

Subjects

Thirty-six healthy males and females were recruited through posted notices and advertisements (28 males, 8 females). Subjects were screened over the telephone and excluded from participating in the study for the following reasons: smoking, and/or health problems (e.g. hypertension, asthma, and CAD) (See appendix for screening criteria). Subjects were also excluded for use of prescription or over-the-counter medications that may affect physiological or psychological responses to stress (e.g., beta-blockers, antidepressants, birth control pills). Potential subjects were also excluded from the study for heavy caffeine use (over 5 servings a day) or if they reported excessive symptoms of caffeine withdrawal. Subjects were screened over the phone for circadian type using the reduced Morningness-Eveningness Questionnaire (rMEQ) (Adan and Almirall, 1991) (see appendix). This reduced scale consists of items 1, 7, 10, 18, and 19 of the original MEQ (Horne and Ostberg, 1976) and has been shown to

correlate closely with the original MEQ. This scale was used for the telephone screening in order to reduce the total screening time. Subjects were accepted into the study with scores of 17 or above (Morning types) and scores of 11 or below (Evening types). Subjects with scores between 12 and 16 were excluded as intermediate types. Subjects were also restricted by age, with subjects ranging in age from 21 to 40 with the average age of 29.4 years $\pm$ 5.3.

Design

A within-subject design across time of day (AM/PM) with Morningness-Eveningness as a between-subjects factor was employed. Subjects came to the laboratory for two sessions, one at 7:30 a.m. and the other at 3:30 p.m. The 3:30 p.m. time was chosen so that the actual task portion of the study would begin after 4:00 p.m. Studies have shown that this may be the time at which crossover for certain variables have been found to occur, such that Morning subjects show decreased responses and Evening subjects will show increased responses after this time (e.g. Wilson, 1990). The two sessions were counterbalanced across circadian type, such that half of each group was tested first during the AM and the other half was tested first during the PM. Gender was also counterbalanced so that there were equal percentages of men and women in each cell. The two sessions were scheduled

approximately four weeks apart (mean = 30 days, range = 13-70 days). This was particularly important for the women, so that they were tested in the same phase of their menstrual cycle (follicular phase, days 5-11 of the menstrual cycle). This stage was determined by self-reports of onset of menses. Subjects were given instructions regarding activities to avoid before coming to the lab (e.g., exercise, caffeine, alcohol) and were instructed to eat a small meal or snack beforehand. Once in the laboratory, experimental procedures were explained and informed consent obtained (see appendix). Subjects underwent a maximum handgrip test using a Dynamometer (GAMER model 1), and then filled out the following questionnaires:

1. Morningness-Eveningness Questionnaire. This 19-item scale was designed to assess what time of day people feel best, and when they prefer to engage in a variety of activities (Horne and Ostberg, 1976).

2. Eysenck Personality Questionnaire. This 57-item questionnaire is designed to assess an individual's levels of Introversion/Extroversion and Neuroticism (Eysenck and Eysenck, 1963 - Educational and Industrial Testing Service, San Diego, CA) (Eysenck and Eysenck, 1968). Past research has been inconclusive regarding the relationship of I/E to Morningness/Eveningness. This study will provide further data to help resolve this debate.

3. Daily Activities Questionnaire. This questionnaire is designed to discover what types of activities people engaged in on the day of their session (e.g., waketime, eating, physical activity). This questionnaire will be given to ascertain whether subjects followed pre-session instructions regarding activities that may alter reactivity (e.g. exercise, caffeine use, nicotine, etc.) (see appendix).

4. Daily Hassles Questionnaire. This 118-item questionnaire assesses the number and severity of a variety of daily hassles.

5. Perceived Stress Scale. This 14-item scale assesses the amount of perceived stress occurring in the prior month.

ECG leads were attached and a blood pressure cuff was attached to the non-dominant arm. Subjects then underwent an initial rest period of twenty minutes during which they were instructed to sit quietly and relax as much as possible. Baseline measures of blood pressure were taken every two minutes during the last ten minutes of the rest period. Heart rate was recorded continuously throughout the entire laboratory procedure. The two mental tasks were counterbalanced with an intervening ten-minute rest. A proofreading performance test was administered following the mental stress task to assess aftereffects. The physical

handgrip was performed last, following a second ten-minute rest period. Because the handgrip is primarily a physical task, it was unnecessary to counterbalance it with the other two mental tasks. Self-reports of stress were obtained following each rest period and each task. Following the session subjects were paid for their participation ($15 for session 1 and $35 for session 2) and debriefed. Subjects were then given a packet of questionnaires to complete at home and mail in, including the following:

1. The Multidimensional Personality Questionnaire. This 300-item scale assesses eleven personality dimensions and three "higher order traits" of positive affectivity, negative affectivity, and constraint (Tellegen, 1982).

2. The Marlowe-Crowne Social Desirability Scale. This 33-item scale assesses people's need to report socially desirable behaviors (Crowne and Marlowe, 1964).

3. The Cook-Medley Hostility Inventory. This 50-item scale assesses people's tendency to view the world in a negative manner (Barefoot et al., 1989).

Tasks

1. Stroop. This is a computerized task consisting of the Stroop color-word task which consists of the listing of the name of a color (e.g., blue) written in a different color (e.g., red). The subjects' task is to pick the word on

the bottom of the screen that spells the color of the word on top. The difficulty of the task adjusts to the level of performance exhibited by the subject. This task was chosen because it was found to increase both cardiovascular and psychological responses in the pilot data described earlier. Furthermore, this task provides performance data by computing the mean reaction time, the number of correct responses, the number of non-responses, and the number of error responses. The task lasts a little over five minutes.

2. Continuous Performance Test (CPT). The CPT is a test of sustained attention, frequently used to measure attention deficits. The CPT consists of a variety of tests, two of which are used in this study (Sunrise Systems, Inc., 1991). The Visual Degraded X task consists of a visual display of an X, with some of the pixels missing, making the X unclear (30% degraded). The subject is instructed to respond when they detect an X. Performance (e.g. errors of omission and commission) and reaction time can be assessed. The visual stimuli are viewed on a two square inch screen of green LEDs, with the stimulus displayed at 189 frames per second. The total number of stimuli given in this study was 380 with 76 criticals (X) yielding a critical stimulus probability of 20%. The stimulus duration was 200 msec with an available response time of 700 msec. During the Auditory Degraded O, subjects are instructed to respond when they

believe they hear the letter "O" in a series of "fuzzy" letters. The bandwidth of the auditory stimuli is 300 to 3000 Hertz. The stimulus parameters are similar to those of the visual stimuli. A variety of research has used the CPT to assess attentional processes (e.g., Mirsky and Kornetsky, 1964; Mirsky, 1987; and Cornblatt, Risch, Faris, Friedman, and Erlenmeyer-Kimling, 1988). This task was chosen as a way of examining potential differences in the ability to sustain attention between Morning and Evening subjects across the day. Variations in attentional processes may be one potential mechanism by which Morningness-Eveningness can explain differing circadian rhythms depending upon the individual's circadian type.

3. Handgrip. Subjects were instructed to grip the dynamometer for 30% of their maximum for one and a half minutes. This task was chosen as a way to examine physical responses (independent of psychological responses) and how they might vary across time of day and circadian type.

Independent Variables

Subjects were classified as Morning or Evening based upon the average of the Morningness-Eveningness Questionnaire scores obtained from sessions 1 and 2. While the two scores were not expected to be significantly different, the average was taken in order to assure the best

estimate. The MEQ has been shown to have good reliability (.89) over time (Posey and Ford, 1981). Subjects were screened before the study to obtain equal numbers of Morning and Evening subjects. Eighteen Morning and eighteen Evening subjects were recruited into the study using the rMEQ. One Morning subject did not return for their second session, leaving 17 Morning subjects. While the rMEQ was found to be highly correlated with the average of the two MEQ scores (r=.96), eight subjects who were classified as Morning or Evening subjects by the rMEQ were actually intermediate types on the full scale. Analyses were performed with the MEQ circadian type sample (N=27) as well as the sample as a whole (N=35), in which case circadian type was determined by the rMEQ.

Dependent Variables

Continuous heart rate was obtained though 2-lead electrodes attached to the subject. Electrocardiogram (ECG) was recorded using a Grass Model 78G Polysomnograph using the 7P511L amplifier (Grass Instrument Company) with the signal output routed to the Vagal Tone Monitor-II (Delta-Biometrics, Inc).

Blood pressure was assessed using the Dinamap Vital Signs Monitor (Critikon). Measurements were taken every two minutes during the last ten minutes of the rests, and every

two minutes throughout the tasks. Rate pressure product, a measure of cardiac demand, was computed by multiplying heart rate by systolic blood pressure.

Self-reports of psychological states were obtained following each task and rest period. A visual analog scale was used and subjects were instructed to mark on a 10 cm line how they feel. One end of the line represented "not at all" and the other end represented "extremely". A variety of psychological states were assessed including: anxious, angry, interested, frustrated, tired, challenged, irritated, bored, happy, and depressed (see appendix).

Reaction times obtained from the CPT and Stroop, as well as performance measures were also analyzed. Performance on the CPT was assessed using the number of errors of commission and omission. Performance on a proof-reading task, including the number of errors found and the percentage of total possible errors, was used to assess aftereffects of stress.

Power Analysis

To ascertain the number of subjects necessary to detect an effect, the computer program SOLO Power Analysis by BMDP Statistical Software, Inc. (1992) was used. Because the interaction between time of day and Morningness-Eveningness is of primary importance, power was computed for this

interaction. The program chosen was for Repeated Measure ANOVA. The effect size of .54 was computed using data from the pilot study for systolic blood pressure. Alpha was set at .05, so that results would be found by chance only 5% of the time. Based on these criteria, 15 Morning subjects and 15 Evening subjects (total N = 30) each run twice produces a Beta of .1854 and Power of .81460. A power level above .80 is considered adequate in detecting potential effects.

Statistical Analyses

Data was transferred to a VAX computer system and analyzed with the SAS statistical package (SAS/STAT, Version 6, 1990). Task (rest, Stroop, and handgrip) and time of day (AM, PM) were analyzed as within-subject factors and circadian type (Morning, Evening) as a between-subjects factor using a 3x2x2 repeated-measures analyses of variance (ANOVA). Multivariate analysis of variance (MANOVA) was performed using SPSS/PC+. For analyses of Hypothesis 1 (that responses will be greater in the AM) ANOVAs were performed with repeated measures across task (rest, Stroop, and handgrip) and session (AM vs. PM). Hypothesis 2 (that circadian type will interact with time of day) was tested by adding the between-groups factor of MEQ (Morning, Evening) to the Task by Time of day analyses. These analyses were performed on all of the cardiovascular variables (SBP, DBP,

HR, and RPP) and for the self-reports of the psychological variables. The Continuous Performance Test was not expected to produce physiological responses and therefore was analyzed only with respect to performance. To protect against Type I error MANOVA was performed first on the cardiovascular variables (SBP, DBP, and HR). Rate pressure product (RPP) was excluded from this analysis since it is computed directly from SBP and HR. To control for possible violations of the sphericity assumption related to repeated-measures designs, a multivariate approach was used in the ANOVAs (Vasey and Thayer, 1987). Manipulation checks were performed to determine whether the stress tasks significantly increased cardiovascular and psychological responding. Post-hoc comparison of means were conducted using planned contrasts for the manipulation checks of the stress tasks. The Bonferroni inequality was used in post-hoc comparisons of AM/PM differences to control for type I error. Analyses of significant interactions were performed using simple effects tests. Comparisons between groups (MEQ) were done using Tukey's Studentized Range Tests.

Change scores were computed by subtracting resting levels from task levels, and were analyzed using a 2x2x2 design (Task x Time of day x MEQ). Correlations did not reveal a consistent significant relationship between baseline levels and change scores. Furthermore, the

baselines for all of the physiological variables (SBP, DBP, HR, and RPP) were not significantly different between groups as analyzed by Tukey's tests. Therefore, the repeated-measures analyses for change scores and levels did not covary for resting levels.

Hypotheses 3 and 4 regarding performance measures were also analyzed using repeated measures designs. The Continuous Performance Test was analyzed using repeated-measures designs across modality (visual, auditory), and time of day (AM, PM), and by circadian type. Variables that were analyzed include: reaction time, correct responses, incorrect responses, and omissions. The CPT was also analyzed by block, with comparisons made across measures divided into four time segments. The proofreading task was also analyzed by time of day (AM, PM) and circadian type (MEQ).

Questionnaires completed in the laboratory were analyzed using a 2x2 repeated measures design (AM/PM x MEQ). Because it is not known at what time the questionnaires at home were completed, these scores were averaged and compared across circadian type using t-tests. Circadian type was determined using the MEQ as described earlier, with 8 intermediate types excluded from analyses. In some cases, where differences occurred, the results examining the whole sample will be reported where MEQ status was based on the

rMEQ in addition to the analyses based on the overall MEQ score.

RESULTS

Cardiovascular Levels

Multivariate analyses of variance (MANOVA) with repeated measures were performed on levels of cardiovascular variables (SBP, DBP, and HR) to control for Type I error. Results revealed a significant overall effect for Task, $F(2,24) = 130.0$, $p<.0001$, showing that the tasks significantly increased cardiovascular variables from rest. Furthermore, there was an overall interaction of time of day (AM/PM) and Task, $F(2,24) = 4.22$, $p<.05$ on the cardiovascular variables. However, the overall AM/PM main effect was not significant. MANOVA also revealed an interaction between time of day (AM/PM) and circadian type (MEQ) and Task, $F(2,24) = 4.50$, $p<.05$.

Based on the significance of the MANOVA reported above, univariate analyses were performed. Using univariate ANOVA, resting levels were compared for group differences. None of the cardiovascular variables were found to differ at rest by circadian type (MEQ) (See Table 4).

Repeated measures analyses (Rest, Stroop, Handgrip) of cardiovascular levels revealed a significant main effect of

task for systolic blood pressure (SBP), $F(2,24) = 45.07$, $p<.0001$, diastolic blood pressure (DBP), $F(2,24) = 181.6$, $p<.0001$, heart rate (HR), $F(2,24) = 51.67$, and rate pressure product (RPP), $F(2,24) = 90.67$, $p<.0001$ (See Table 3). These main effects were due to significant increases from rest to levels obtained during the Stroop task and the handgrip task for all of the cardiovascular measures.

Significant main effects for time of day (AM/PM) emerged for HR, $F(1,25) = 4.30$, $p<.05$ and a marginally significant effect for RPP, $F(1,25) = 3.69$, $p=.06$. However, in contrast to the hypothesis predicting greater levels during the AM hours, PM levels were found to be greater during the Stroop task. DBP showed an AM/PM interaction with Task $F(2,24) = 8.22$, $p<.01$, such that the Stroop produced greater reactions during the AM and the handgrip task produced greater levels in the PM (non-significant using Bonferroni inequality). SBP also revealed a marginally significant interaction between time of day (AM/PM) and Task, $F(2,24) = 3.34$, $p=.05$. No main effects for circadian type (MEQ) were found.

Although no significant interactions were revealed between AM/PM and MEQ, three-way interactions were found for AM/PM, Task, and MEQ for RPP, $F(2,24) = 3.42$, $p<.05$, and a marginal effect for SBP, $F(2,24) = 3.10$, $p=.06$ (See Table 4). Means show that Morning subjects reached higher levels

during the AM than the Evening subjects did. Heart rate, although not significant, showed the predicted pattern of results, while DBP showed no such pattern (See Figures 6-7). Analyses of the sample as a whole revealed similar results, with the three-way interaction for AM/PM, Task, and MEQ also found for RPP, $F(2,31) = 3.10$, $p<.05$ and SBP, $F(2,32) = 2.90$, $p=.06$.

Cardiovascular Change Scores

Multivariate analyses of variance (MANOVA) with repeated measures was performed on change scores (task minus resting levels) for the cardiovascular variables (SBP, DBP, and HR) to control for type I error. Results revealed a significant Task effect, $F(1,25) = 6.61$, $p<.05$. While the overall AM/PM effect was not significant, $F(1,25) = 2.40$, $p=.13$, time of day (AM/PM) did interact with Task, $F(1,25) = 6.88$, $p<.05$. Time of day (AM/PM) was also found to interact with circadian type (MEQ), $F(1,25) = 9.33$, $p<.01$.

Using ANOVA with repeated measures, analyses of change scores (task minus resting levels) revealed significant main effects for Task for DBP, $F(1,25) = 27.38$, $p<.0001$ and RPP, $F(1,25) = 9.04$, $p<.01$, with greater changes achieved during the hand grip task than the Stroop task (See Table 5). Significant main effects were also found for time of day (AM/PM) for DBP, $F(1,25) = 4.91$, $p<.05$ with the Stroop task

producing greater changes during the PM session than during the AM session. Time of day (AM/PM) interacted with Task for SBP, $F(1,25) = 5.75$, $p<.05$. No significant main effects were found for circadian type (MEQ).

The predicted interaction between MEQ and AM/PM was found for SBP, $F(1,25) = 5.71$, $p<.05$, and RPP, $F(1,25) = 6.66$, $p<.05$. Change scores show that Morning subjects show greater reactions during the AM session while Evening subjects show greater reactions during the PM session (See Figures 8-9). HR also showed results in the direction of the predicted interaction, however it did not reach significance in the sample of Morning and Evening subjects, $F(1,25) = 2.62$, $p=.11$.

Self-Reported Psychological State

Repeated measures analyses of variance on self-reports of psychological states during rest and tasks revealed a significant main effect of Task for "anxious", $F(2,24) = 33.40$, $p<.0001$, "frustrated", $F(2,24) = 39.97$, $p<.0001$, "interested", $F(2,24) = 18.04$), $p<.0001$, "tired", $F(2,24) = 30.46$. $p<.0001$, "happy", $F(2,24) = 5.61$, $p<.01$, "angry, $F(2,24) = 14.19$, $p<.0001$, "bored", $F(2,24) = 8.89$, $p<.01$, and "challenged", $F(2,24) = 116.72$, $p<.0001$. Subjects rated the tasks higher than the rest for "anxious", "frustrated", "interested", "angry", and "challenged", while the rest

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period received higher ratings for "happy" and "bored" (See Table 7 and Figures 10-14).

Main effects for time of day (AM/PM) were found for "frustrated", $F(1,25) = 4.50$, $p<.05$, when the Morning and Evening subject sample was examined. For the sample as a whole, including intermediate types, "anxious". $F(1,33) = 3.85$, $p=.05$ also revealed differences depending upon the time of day. Means revealed that subjects reported higher levels of "frustrated" and "anxious" during the AM hours.

Analyses revealed main effects for circadian type (MEQ) for "frustrated", $F(1,25) = 4.55$, $p<.05$, "tired" $F(1,25) = 6.85$, $p<.05$, and "irritated", $F(1,25) = 5.72$, $p<.05$. Means reveal that Evening subjects report higher levels of these feelings regardless of time of day (See Table 8). Marginally significant effects were found for "happy", $F(1,25) = 3.31$, $p=.08$, and "bored", $F(1,25) = 3.32$, $p=.08$. Means reveal greater levels of "bored" for Evening subjects and greater levels of "happy" for Morning subjects.

A marginally significant interaction was found between time of day (AM/PM) and circadian type (MEQ) for "interested", $F(1,25) = 3.73$, $p=.06$. This interaction occurred during the Stroop task, with Morning subjects showing more interest during the AM session and Evening subjects reporting more interest during the PM session. Three-way analyses of time of day (AM/PM), Task, and

circadian type (MEQ) revealed significant effects for "bored", $F(2,24) = 6.30$, $p<.05$, with Evening subjects reporting greater levels of "bored" during rest in the PM session and Morning subjects reporting higher levels during the AM.

Change in Self-Reported Psychological State

Change scores (task minus resting levels) were examined in self-report variables using 2x2x2 repeated measures ANOVAs (Task x AM/PM x MEQ). Main effects for Task were found for "anxious", $F(1,25) = 58.70$, $p<.0001$, "frustrated", $F(1,25) = 40.14$, $p<.0001$, "interested", $F(1,25) = 33.20$, $p<.0001$, "depressed", $F(1,25) = 6.36$, $p<.05$, "angry", $F(1,25) = 18.09$, $p<.001$, "challenged", $F(1,25) = 21.36$, $p<.0001$, and "irritated", $F(1,25) = 33.76$, $p<.0001$. Means show that subjects report greater changes during the Stroop task for "anxious", "frustrated", "interested", "angry", and "challenged", while the handgrip task revealed greater decreases in "happy" (See Table 9).

No significant main effects were found for time of day (AM/PM). However, main effects for circadian type (MEQ) were found for "bored", $F(1,25) = 6.35$, $p<.05$, and marginal effects were found for "frustrated", $F(1,25) = 4.14$, $p=.05$, and "irritated", $F(1,25) = 2.92$, $p<.10$. Means reveal that Evening subjects show greater increases in "frustrated" and

"irritated" and greater decreases in "bored" (See Table 10, See Figures 15-19).

Interactions between MEQ and AM/PM reveal significant effects for "bored", $F(1,25) = 13.03$, $p<.01$. Means show that Evening subjects become less bored during the task in the PM session. Marginal effects were found for "happy", $F(1,24) = 3.42$, $p=.07$, and "challenged", $F(1,25) = 3.63$, $p=.06$. Evening subjects became less "happy" during the AM session and Evening subjects report being more "challenged" in the PM session. Three-way interactions of AM/PM, Task, and MEQ indicate marginal effects for "anxious", $F(1,25) = 3.89$, $p=.05$, and "frustrated", $F(1,25) = 3.05$, $p=.07$, with Evening subjects showing greater changes in "frustrated" during the AM than the Morning subjects.

Performance Variables

Scores derived from the test of sustained attention, The Continuous Performance Test, were examined using repeated-measures analyses of variance. A 2x2x2 ANOVA (Task (visual/auditory) x AM/PM x MEQ) was performed on each of the dependent measures. Session effects were not found across session 1 and 2 suggesting that a practice effect did not occur. Marginal main effects for time of day (AM/PM) were found for the number of correct responses $F(1,24) = 3.86$, $p=.06$, number of omissions, $F(1,24) = 4.18$, $p=.05$, and

mean reaction time, $F(1,24) = 3.56$, $p=.07$. Inspection of the means (See Figures 20-21) indicate that correct responses appear to be greater in the PM for the auditory task while omissions appear to be greater during the AM for the auditory task (non-significant using Bonferroni inequality). Reaction time was found to be faster during the PM session for the visual task. These results confirm that the auditory and visual tasks are not equivalent in the Sunrise system.

Main effects were also found for type of task for correct responses, $F(1,24) = 4.08$, $p=.05$, incorrect responses, $F(1,24) = 5.75$, $p<.05$, reaction time, $F(1,24) = 31.2$, $p<.0001$, and number of omissions, $F(1,24) = 4.00$, $p=.05$. Means show that the number of correct and incorrect responses were greater for the visual task and reaction time was faster for the visual task, regardless of time of day. The number of omissions were greater for the auditory task.

No main effects were found for circadian type (MEQ). Similarly, the predicted interaction between circadian type and time of day was not found for any of the CPT variables.

Because the CPT is a test of sustained attention, it is of interest to examine changes across blocks to determine whether patterns emerge across time that may not be apparent in looking at the total scores. When the CPT was analyzed by repeated-measures across 4 blocks, marginal AM/PM effects

were found for auditory correct responses, $F(1,24) = 2.93$, $p<.10$, auditory reaction time, $F(1,24) = 3.39$, $p=.08$, visual reaction time, $F(1,24) = 6.2$, $p<.05$, auditory omissions, $F(1,24) = 3.29$, $p=.08$, auditory percent correct, $F(1,24) = 2.86$, $p=.10$. Post-hoc comparisons showed block 3 to be where the differences existed for percent correct (PM greater) and the number of omissions (AM greater). Means suggest that reaction time may be faster in the PM. No significant interactions were observed across block by time of day (AM/PM) and circadian type (MEQ).

Performance on the proofreading task was also analyzed. Total number of errors found, as well as the percentage of total possible errors found, were analyzed in a 2 x 2 design (time of day by circadian type). Analyses indicated no significant main effects or interactions.

The Stroop task was also analyzed for performance. While no AM/PM by MEQ interactions were found for the Stroop, several MEQ main effects were observed (See Figures 22-23). Main effects for circadian type (MEQ) were found for the number of trials completed, $F(1,25) = 5.17$, $p<.05$, number of correct responses, $F(1,25) = 5.71$, $p<.05$, reaction time , $F(1,25) = 3.16$, $p=.08$, and maximum response window, $F(1,25) = 5.05$, $p<.05$. Tukey's studentized range tests revealed that Evening subjects completed more trials, more correct responses, and had a quicker reaction time during

the PM session. Morning subjects had a greater maximum response window during the PM sessions (indicating worse performance).

Personality Variables

Analyses of personality self-report questionnaires were performed to look for potential differences between Morning and Evening subjects. Repeated-measures 2x2 ANOVAs were performed on questionnaire data taken during the AM and PM sessions. Extroversion, neuroticism, daily hassles, and perceived stress showed no significant main effects or interactions when analyzed for the Morning and Evening subject sample. When the sample was analyzed as a whole, number of daily hassles, $F(1,31) = 2.77$, $p=.10$ and severity of daily hassles, $F(1,31) = 3.19$, $p=.08$, were marginally significant for circadian type (rMEQ) with Evening subjects reporting greater daily hassles. T-tests were performed on the average (session 1 and session 2) of the scores of the questionnaires completed at home. Results show significant differences for the Crowne-Marlowe, $p<.05$, with Morning subjects scoring higher. The Taylor anxiety scale showed marginally significant differences ($p=.07$) with Evening subjects reporting higher levels. Two subscales of the Multidimensional Personality Questionnaire showed significance. The MPQ stress subscale showed significant

differences between circadian type (MEQ), $p<.05$ with Evening subjects reporting greater stress levels. The MPQ harm avoidance subscale ($p<.05$) revealed Morning subjects reporting higher levels of harm avoidance. Overall positive and negative affect did not differ between Morning and Evening subjects.

Daily Activities and Subject Characteristics

Subjects as a whole were examined for differences in health habits and in daily activities in general and preceding the lab sessions. T-tests reveal that the Morning subjects in this sample were older than the Evening subjects (32 years vs. 27 years, $p<.01$). Male and female subjects were not found to differ on MEQ scores, and self-reports of the number of servings of caffeine and alcohol were not found to differ between Morning and Evening subjects in this sample.

Sleep variables were examined, and significant differences were found between Morning and Evening subjects. Sleep the night before the PM session was examined because it was presumed to be closest to normal. This is in comparison to the morning session when subjects were required to wake up to come to the laboratory, which may have interfered with a normal sleep pattern, particularly for the Evening subjects. Morning subjects reported going

to sleep earlier (11:07 PM vs. 12:29 AM, $p<.05$) and waking up earlier (06:22 AM vs. 07:59 PM) the day of the PM session. The total amount of sleep was also compared before both the AM and PM session by circadian type. An AM/PM main effect was found $F(1,33) = 6.6$, $p<.05$, with less sleep occurring before the AM session. Tukey's test reveals that Evening subjects received significantly less sleep before the AM session than the Morning subjects did (5.7 hours vs. 6.8 hours). Analyses based on the rMEQ classification revealed similar findings.

DISCUSSION

Hypothesis 1 predicted that physiological and psychological variables would exhibit a circadian variation, with higher levels and reactivity during the morning session. This hypothesis received some support for psychological states, with "frustration" and "anxiety" levels being reported higher during the AM session (See Table 11 for a summary of the complete results). However, change in response to the tasks did not reveal any time of day differences. Physiological data, although significant, was opposite of the predicted direction. Some of the cardiovascular levels and change scores were greater during the PM session as compared to the AM session.

Hypothesis 2 predicted an interaction between circadian type (MEQ) and time of day (AM/PM). This hypothesis received support from both the physiological and psychological data. Rate pressure product and systolic blood pressure revealed levels and change scores showing the predicted interaction between circadian type (MEQ) and time of day (AM/PM). Overall, these data suggest that Morning subjects exhibit greater responses during the AM session, and Evening subjects show greater responses during the PM session. Psychological self-report levels showed interactions between time of day (AM/PM) and circadian type (MEQ) for "bored" and "interested". Interactions for change scores were found for "bored", "happy", "challenged", "anxious", and "frustrated".

Hypothesis three, that attention would vary across time of day by circadian type, was not supported by these data. However, attention was found to vary across time of day, such that attentional resources were more effectively allocated in the PM session. Hypothesis four, concerning aftereffects of stress on performance, was not supported by this data.

Morning and Evening subjects were found to differ on a variety of parameters. Self-report of psychological states found Evening subjects to report higher levels and/or changes of "frustrated", "irritated", "tired" and "bored".

While Morning subjects reported higher levels of "happy". Performance was found to vary by circadian type, with Evening subjects performing better on the Stroop. A variety of personality and behavioral parameters were examined which suggest Evening subjects report higher levels of anxiety and stress in their daily lives. Gender and substance use were not found to vary by circadian type, but a variety of sleep parameters did.

Results of the present study indicate that cardiovascular and affective responses to stress may exhibit a circadian variation. Negative affect, as represented by levels of frustration reached during the Stroop task, was higher during the AM session. In contrast, cardiovascular levels (SBP and DBP) and change scores (DBP) showed greater responses during the afternoon session. This corresponds to previous research which suggests that psychological states such as tense arousal (Caminada and DeBruijn, 1992), and anxiety (Margraf, 1990) occur at higher levels during the morning hours, while positive affect is low (Clark, Watson, and Leeka, 1989). As this study shows, stress can lead to greater levels of negative psychological states (frustration). Therefore, stress may contribute to the findings of circadian variations in negative affect, in general, and in anxiety attacks as a health outcome.

In contrast, cardiovascular levels (SBP and RPP) and

cardiovascular change scores (DBP) showed greater responses during the late afternoon session. These findings, however, were not as predicted. Previous research suggests that certain physiological parameters related to cardiovascular functioning may be higher during the morning hours. Blood pressure, heart rate, catecholamines, and cortisol all have been found to increase and/or peak during the morning hours (Millar-Craig, Bishop, and Raftery, 1978; Turton and Deegan, 1974; and Weitzman et al., 1971). Furthermore, a variety of clinical cardiovascular events have been found to peak in the morning hours. Sudden death, myocardial infarction, and myocardial ischemia all have been shown to peak in the morning hours (e.g. Muller et al., 1987; Muller et al., 1985; and Rocco et al., 1987). Thus, the findings of an afternoon peak in cardiovascular reactivity to stress do not appear to correspond with prior physiological findings and clinical events. However, several studies examining the circadian variation of clinical cardiovascular events have also found a secondary afternoon peak in events (Muller et al., 1987; Muller et al., 1985; and Mulcahy et al., 1988). Cardiovascular events occurring during the morning hours may occur at a lower threshold, with lower levels of cardiovascular demand triggering an event. However, events in the late afternoon may occur at higher levels of cardiovascular demand in response to stress. Thus, the

findings of greater cardiovascular responses to stress in the late afternoon may not be inconsistent with prior cardiovascular findings.

As already stated, these findings suggest that in the subject population studied, cardiovascular responses to stress do not occur at higher levels during the morning, but rather in the afternoon. Does stress somehow alter the predicted physiological response? Do perceptions of stress vary with the time of day to produce differing responses? If attention varies across time this might help explain different stress responses. The Continuous Performance Test, a test of sustained attention, revealed that attention did vary across the day with higher levels of attention, as shown by performance and reaction time, found during the afternoon session. This finding might help to explain why negative affect reaches greater levels during the morning hours. If attention is decreased and performance suffers, this can lead to increases in frustration. Alternatively, high levels of frustration and anxiety at rest might interfere with attention and performance during the task. However, this cannot be the complete explanation as performance and affective responses were not significantly correlated in this sample. Perceptions of stress may also vary with attention. If attention is low, stress may be less likely to be perceived, thus avoiding the stress

process. Coping ability may also vary with the time of day, thus leading to differing responses.

Interestingly, although the CPT revealed attentional variations across the day the Stroop task did not. However, these two tasks appear to measure different aspects of attention. Mirsky (1987) suggests that the CPT is a test of sustained attention or vigilance, while the Stroop task emphasizes the ability to focus. These results show that vigilance may be reduced during the morning hours, whereas focus remains unaffected. Thus, the results of this study suggest that vigilance may be more susceptible to circadian variations than one's ability to focus on a task. This has implications for jobs requiring vigilance throughout the day, where performance may be adversely affected during the morning hours.

Other variables may have interfered with attention and increased negative affect during the morning hours. Subjects, as a whole, reported less sleep before the morning session, which may have interfered with attention and ability to perform. Also, even though subjects were screened to eliminate excessive caffeine use and caffeine withdrawal symptoms, some subjects reported missing their "morning" cup of coffee before the AM session. However, for the PM session subjects could still partake of their morning caffeine since they could consume caffeine until noon of

that day. Thus, the AM caffeine restriction may have interfered with performance and contributed to negative psychological states. However, the findings of higher negative affect during the morning in subjects not caffeine restricted (Caminada and DeBruijn, 1992) suggest that this was not the primary cause of the circadian variations observed in this study.

The implications of the present findings for research methodology are clear. When looking at most dependent variables in human research, it is common practice to control for time of day. This research shows that psychological and physiological states and responses to stress, as well as attention/performance all exhibit circadian variations. Frustration was higher during the morning while cardiovascular responses and attention were higher during the afternoon. Therefore, stress researchers need to be aware of how their dependent variable of interest may be affected by time of day. Researchers who wish to get the largest response possible should plan the time of day accordingly. For example, researchers looking at negative affect in response to stress may wish to run their study during the morning hours to optimize potential changes.

Future research in the area of circadian variation in reactivity to stress should extend the time periods examined here and in Nebel et al.'s study (1994), which examined only

the morning and early afternoon hours. The evening and nighttime hours should also be examined as to how they vary concerning reactions to stress. Furthermore, to try to determine what contributes to the circadian variation of reactivity, perceptions of stress and coping ability/ strategies should also be examined. If perceptions of stress and the ability to cope with stress varies across the day this could help explain the circadian variations found in responses to stress.

The circadian variation of responses has been observed in general for affect, cardiovascular responses, and attention, but how do these circadian variations interact with an individual's circadian type (Morning versus Evening types)? These data suggest that cardiovascular and self-report of psychological states vary across time of day depending upon circadian type. Cardiovascular levels (RPP and SBP) reveal interactions between time of day and circadian type, such that Morning subjects reached higher levels during the AM session. Cardiovascular change scores also show an interaction, with morning subjects showing greater changes in the AM and Evening subjects show greater changes during the PM. Thus, these data provide support for the hypothesis predicting an interaction between time of day and circadian type.

The methodological implications of these findings are

more complicated then the implications of the general circadian variation findings reported above. The findings that time of day and circadian type interact to produce different patterns suggest that controlling for time of day is simply not enough to assure that the results are not confounded. As suggested by Nebel et al. (1994) researchers who do not know the circadian type of the subjects involved in their study may be drawing inaccurate conclusions from their data. Studies of aging provide a good example. Several studies have observed a relationship between age and circadian type; as age increases so does Morningness (Mecacci, Zani, Rocchetti, and Lucioli, 1986; Wilson, 1990; Drennan, Klauber, Kripke, and Goyette, 1991; Ishihara et al., 1991). Studies which examine how aging affects psychological and physiological reactivity may inadvertently affect their results by running all of their sessions during the AM (to control for a general circadian variation). However, the groups may now show differences in the morning, not because of age, but because these older subjects are more likely to be morning-oriented. Therefore, it is not only important to control for time of day in general, but for circadian type in particular.

The relationship between circadian type and time of day also has implications for the study of disease processes. Diseases that show a circadian variation, such as

cardiovascular clinical events, may be further explained by examining circadian type. Clinical cardiovascular events have been shown to have a late afternoon/early evening peak in addition to the predominant morning peak. This may be due to differential effects of time of day on two types of subjects (Morning and Evening types) such that clinical events occur more frequently in the a.m. for Morning types and in the p.m. for Evening types. As seen in this research these subjects differ in their physiological and psychological responses to stress depending upon the time of day. This finding, in addition to variations in activity across the day, suggest that circadian type might influence the peaks in these disease endpoints. This is supported by the pilot data described earlier in Tables 1 and 2 which shows that the pattern of myocardial ischemia in daily life occurs differently depending upon circadian type. Morning subjects show greater numbers of ischemic events as well as total duration of ischemia during the first twelve hours of the day, whereas Evening subjects show more ischemia in the last twelve hours of the day. Differing responses to stress across the day may contribute to the occurrence of these clinical events.

Other clinical problems that show a circadian variation include panic attacks (Margraf, 1990) and asthma (See Van Aaldern, Meijer, Oosterhoff, and Bron, 1993). These

conditions may also vary with circadian type with Morning and Evening subjects contributing differently to the variations found. Both of these conditions can also be affected by the stress response. Therefore, because Morning and Evening people are affected differently by stress at different times of the day, the triggering of an event may also differ across the day depending upon circadian type.

Surprisingly, attention, as measured by the CPT, did not reveal an interaction between time of day and circadian type. It was expected that attention might be the mechanism by which circadian type interacted with time of day. As described earlier, ERP, an indicator of the allocation of attentional resources, varies with circadian type and time of day (Zani, 1986; Geisler and Polich, 1992). Furthermore, self-reports of arousal also vary with circadian type and time of day (e.g. Watts, Cox, and Robson, 1983. Therefore it was expected that attention, as measured by CPT performance, would also show the predicted interaction.

A possible reason exists to explain the lack of a significant interaction between time of day and circadian type on the CPT performance. It is possible that by the CPT alone was not challenging enough to show differences between subject types depending upon time of day. Support for this idea comes from studies of a noise stressor on task performance. Finkelman and Glass (1970) examined the

effects of stress on performance by overloading the subject with a two-task paradigm. Subjects had a primary task, which they could perform error free, even under stress. However, when a secondary task was added, overload occurred and stress differences were observed (Finkelman & Glass, 1970; Glass & Singer, 1972). Therefore, the CPT in combination with a secondary task might overload subjects enough that differences will be found for circadian type by time of day.

Do the interactions reported above between circadian type and time of day support the model of circadian phase suggested earlier (Figure 1)? An interaction was found between circadian type and time of day for physiological and psychological responses to stress which does provide initial support for the model of phase shifts. However, since only two time points were examined actual phase shifts cannot be observed. For phase shifts across Morning and Evening types of people to be examined, multiple or continuous time points across the circadian cycle are necessary. Furthermore, to determine at what point Morning and Evening subjects "crossover" and begin to differ in their responses to stress cannot be established from this study. Again, multiple measures across the day are essential for such a determination.

Several main effects were found for circadian type.

While, no physiological differences were found between Morning and Evening types, several self-reported psychological state differences emerged between Morning and Evening types. Evening subjects reported higher levels of "frustrated", "irritated", "bored", and "tired" regardless of the time of day, whereas, Morning subjects reported higher levels of "happy". Similarly, change scores revealed greater increases in "frustrated" and "irritated", and decreases in "bored" for the Evening subjects.

The self-report findings described above show Evening subjects to be higher in negative affect (frustrated, irritated, and less happy) than Morning subjects regardless of time of day. In conjunction with these findings, personality questionnaires were examined for group differences in daily life. Although some of the results are marginally significant, the data suggests that Evening subjects are higher in anxiety, stress, and daily hassles.

The personality findings found in this study are consistent with research done by Matthews (1988) in which Evening subjects were found to be higher in anxiety. Matthews suggests that anxiety may interfere with the perception of time cues and cause a shift toward Eveningness. Levy (1985) found Evening subjects to be higher in pessimism and suggest that this may lead to phase shift because subjects simply don't want to get out of bed

in the morning. Similarly, Ishihara et al. (1985) reported higher levels of substance use (caffeine, nicotine, and alcohol) in Evening subjects. These researchers suggest that substance use may be a mechanism by which circadian type is determined. They suggest that increases in substance use can shift a person's circadian phase, leading to greater Eveningness. Mitchell and Redman (1993) also found that Evening subjects consume more caffeine. The current study found no differences in substance use between circadian types, however, smokers and high caffeine users were excluded from the study and this may have influenced the lack of findings regarding substance use. However, the finding that Evening subjects in this study reported greater levels of stress may be in line with Ishihara et al. (1985). Higher levels of stress may lead to increases in substance use, and an eventual shift toward Eveningness. Furthermore, Evening subjects reported being more "tired" and receiving less sleep that Morning subjects, and this may also be related to their reports of higher stress and negative affect.

If stress does contribute to a shift towards Eveningness, the health implications of this need to be examined. Higher levels of stress, negative affect, fatigue, and substance use may all interact to affect a variety of diseases. Evening subjects may, thus, be more

vulnerable to illness because of these factors. Future research should try to determine if Evening subjects are more susceptible to illness and disease states.

A potential limitation of this study is that the subjects' activities were not controlled prior to coming to the laboratory. While certain activities were kept constant such as refraining from caffeine and aerobic exercise, not all behavior was controlled before the session. Thus, a variety of exogenous factors may have contributed to the findings of this study. To discover the more "endogenous" responses of stress across the day, subjects should be brought into the laboratory the night before the session and have activities (eating, sleeping, etc.) strictly controlled. The conclusions of this study are also limited to the types of stressors and responses studied here, as well as to the two time points studied. Furthermore, caution must be used given the number of statistical tests performed using this small sample size. Sample size was computed based on one effect size rather than the multiple dependent variables used in this study. However, the consistency of these results with the results from the two pilot studies suggest that the effects found here are reliable effects.

In summary, psychological and physiological responses to stress appear to vary with time of day, as does

attention. Circadian type appears to interact with time of day to produce different physiological and psychological patterns. These findings have methodological and clinical importance and should be examined further regarding variations in the perception of stress as well as coping ability. Furthermore, research should extend the findings here which suggest that Evening people may experience more stress. Stress may be a mechanism by which circadian type is altered via increased substance use or some other mechanism and this hypothesis should be addressed in future research. Research with animals suggests that stress can alter circadian rhythms (Steenbergen, Koolhaas, Strubbe, and Bohus, 1989; Kant et al., 1991; Tornatzky and Miczek, 1993). Furthermore, treatments that reduce stress (e.g. music, imagery, and relaxation) have been found to entrain corticosteroid and temperature rhythms under conditions of shift-work (Rider et al., 1985). Women with Seasonal Affective Disorder reported being more Evening oriented, but when treated with morning phototherapy their MEQ scores shifted towards Morningness (Elmore et al., 1993). How stress alters human circadian rhythms and how this might contribute to Eveningness should be examined in future studies, in addition to the health implication of being Evening oriented.

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Table 1

Number of ischemic events by MEQ and time.

	AM	PM
Morning subjects	12	8
Evening subjects	7	22

Chi-Square statistic - p<.011

Table 2

Total duration of ischemia in minutes by MEQ and time.

	AM	PM
Morning subjects	118	88
Evening subjects	39	136

Chi-Square statistic - p<.0001

Table 3

Mean levels of cardiovascular variables.

		AM Session	PM Session
SBP*	Rest	110.5 (9)	110.7 (10)
(mmHg)	Stroop	120.1 (14)**	123.6 (14)**
	Grip	125.6 (13)	124.6 (11)
DBP**	Rest	65.0 (5)	63.2 (6)
(mmHg)	Stroop	72.0 (7)**	75.0 (8)**
	Grip	80.8 (7)*	78.4 (5)*
HR**	Rest	65.2 (11)*	68.4 (15)*
(bpm)	Stroop	75.1 (14)*	78.7 (16)*
	Grip	78.3 (12)*	81.1 (14)*
RPP*	Rest	7226 (1517)	7606 (1836)
(bpm X	Stroop	8755 (1961)**	9388 (2321)**
mmHg)	Grip	9910 (2136)	10164 (2168)

Overall significance of AM/PM or AM/PM x Task is listed in left hand column (** = p<.05, * = P<.10). Post-hoc comparisons listed in AM and PM columns (Bonferroni p <.016 = ***). Standard deviations listed in parentheses.

Table 4
Mean levels of cardiovascular variables by circadian type.

		Morning Subjects		Evening Subjects	
		AM	PM	AM	PM
SBP*	Rest	114.4 (9.1)	114.0 (11.8)	109.4 (8.2)	107.2 (7.7)
mmHg	Stroop	123.6 (14.2)	125.6 (15.9)	116.3 (13.0)	121.5 (11.0)
	Grip	129.0 (13.6)	127.4 (12.8)	121.9 (12.8)	121.5 (7.5)
DBP	Rest	65.1 (6.4)	64.3 (7.3)	64.9 (4.1)	62.1 (4.1)
mmHg	Stroop	73.1 (8.0)	75.7 (8.6)	70.8 (5.7)	74.3 (8.0)
	Grip	81.2 (7.1)	79.0 (5.5)	80.3 (6.6)	77.7 (5.4)
HR	Rest	65.0 (10.8)	67.7 (14.0)	65.3 (12.0)	69.3 (15.9)
bpm	Stroop	76.6 (13.1)	77.8 (14.1)	73.4 (14.6)	79.7 (19.4)
	Grip	79.6 (12.4)	80.0 (15.4)	76.9 (10.7)	82.3 (12.7)
RPP**	Rest	7300 (1643)	7807 (2067)	7146 (1430)	7388 (1605)
bpmx	Stroop	9061 (1732)	9445 (2324)	8424 (2203)	9326 (2411)
mmHg	Grip	10344 (2290)	10281 (2481)	9442 (1936)	10037 (1867)

Significant 3 way interactions between AM/PM x MEQ x Task listed in left hand column (** = p<.05, * = p<.10). Standard deviations listed in parentheses.

Table 5

Mean change scores (task - rest) for cardiovascular variables.

		AM Session	PM Session
SBP**	Stroop	9.6 (10.7)**	12.9 (9.6)**
(mmHg)	Grip	15.1 (9.9)	13.8 (9.4)
DBP**	Stroop	7.0 (5.7)***	11.8 (6.8)***
(mmHg)	Grip	15.7 (5.3)	15.1 (4.9)
HR	Stroop	9.9 (8.9)	10.3 (8.2)
(bpm)	Grip	13.2 (8.6)	12.7 (8.5)
RPP	Stroop	1529 (1167)	1782 (928)
bpm x mmHg	Grip	2684 (1525)	2558 (1446)

Significant overall AM/PM or AM/PM x task effect listed in left hand column (** = p<.05, * = p<.10). Post-hoc comparisons listed in AM and PM column session (Bonferroni p <.025 = ***). Standard deviations listed in parentheses.

Table 6

Mean change scores (task minus rest) for cardiovascular variables.

		Morning Subjects		Evening Subjects	
		AM	PM	AM	PM
SBP**	Stroop	12.2 (12)**	11.6 (12)**	6.8 (8)**	14.3(10)**
(mmHg)	Grip	17.6 (11)	13.4 (9)	12.5 (9)	14.3 (10)
DBP	Stroop	8.0 (6)	11.4 (4)	5.9 (6)	12.2 (9)
(mmHg)	Grip	16.0 (5)	14.7 (4)	15.4 (6)	15.6 (6)
HR	Stroop	11.6 (10)	10.1 (7)	8.1 (7)	10.4 (10)
(bpm)	Grip	14.6 (11)	12.4 (10)	11.6 (6)	13.1 (7)
RPP** (bpm x	Stroop	1762 (1256)**	1638 (670)**	1278 (1038)**	1938 (1153)**
(mmHg)	Grip	3044 (1891)*	2474 (1575)*	2296 (921)*	2649 (1351)*

Significant interaction between AM/PM x MEQ listed in left hand column (** p <.05, * = p <.10). Simple effects tests of interactions listed in AM and PM by MEQ columns. Standard deviation listed in parentheses.

Table 7
Mean levels of psychological self report variables.

		AM Session	PM Session
	Rest	14.5 (14.9)**	9.9 (7.7)**
Anxious	Stroop	41.2 (22.6)	38.3 (20.9)
(mm)	Grip	20.8 (17.9)	16.6 (16.8)
	Rest	10.2 (10.1)	7.6 (5.6)
Frustrated	Stroop	49.3 (23.4)**	43.3 (23.0)**
**	Grip	21.8 (19.8)	17.4 (17.6)
(mm)	Rest	24.8 (20.0)	29.0 (20.0)
Interested	Stroop	52.4 (22.0)	50.8 (20.6)
(mm)	Grip	25.7 (16.9)	27.1 (18.6)
	Rest	39.3 (23.6)	35.5 (18.9)
Tired	Stroop	18.8 (17.1)	14.3 (11.0)
(mm)	Grip	25.2 (23.4)	24.4 (26.4)
	Rest	45.2 (23.6)	49.7 (22.7)
Happy	Stroop	35.4 (25.0)	36.1 (26.5)
(mm)	Grip	32.2 (25.9)	30.8 (26.9)
	Rest	9.9 (12.4)	7.1 (9.1)
Depressed	Stroop	11.8 (13.6)	9.6 (10.6)
(mm)	Grip	7.6 (9.5)	5.2 (4.5)
	Rest	6.2 (4.8)	5.4 (4.5)
Angry	Stroop	20.4 (16.5)	17.5 (19.0)
(mm)	Grip	9.4 (11.5)	8.6 (9.4)
	Rest	23.3 (21.4)	22.6 (22.1)
Bored	Stroop	9.5 (7.5)	11.1 (12.7)
(mm)	Grip	9.8 (9.9)	12.0 (15.3)
	Rest	10.9 (12.0)	10.5 (15.4)
Challenged	Stroop	71.9 (15.1)	71.5 (16.5)
(mm)	Grip	57.0 (23.4)	51.2 (25.4)
	Rest	9.2 (11.8)	6.4 (7.5)
Irritated	Stroop	34.1 (24.1)	31.8 (23.0)
(mm)	Grip	13.9 (16.4)	16.6 (21.6)

Significant overall AM/PM effect listed in left hand column (** = $p<.05$,

* = p<.10). Post-hoc comparisons listed in AM and PM columns (Bonferroni p<.016 = ***). Standard deviations are in parentheses.

Table 8

Mean levels of psychological self report variables by MEQ.

		Morning		Evening	
		AM	PM	AM	PM
Anx.	Rest**	19.9 (19)**	9.7 (9)	8.6 (5)**	10.2 (6)
(mm)	Str.*	44.6 (25)	34.7 (21)	37.6 (21)	42.1 (21)
	Grip	20.7 (19)	18.4 (19)	20.9 (18)	14.6 (15)
Fru.	Rest	11.1 (13)	6.3 (6)	9.2 (5)	9.0 (5)
(mm)	Str.	47.9 (24)	36.8 (25)	50.7 (24)	50.3 (20)
	Grip	12.8 (13)**	10.2 (14)**	31.5 (22)**	25.2 (18)**
Int.	Rest	25.7 (15)	24.0 (20)	23.8 (25)	34.3 (20)
(mm)	Str.	58.6 (14)	48.1 (21)	45.6 (27)	53.8 (20)
*	Grip	28.6 (18)	28.0 (19)	22.6 (15)	26.2 (19)
Tir.	Rest	28.4 (21)	30.9 (22)	51.0 (21)	40.4 (13)
(mm)	Str.**	12.1 (16)	14.8 (13)	26.1 (15)	13.8 (9)
	Grip	19.9 (24)	20.4 (23)	30.9 (22)	28.8 (30)
Hap.	Rest	46.4 (24)	56.0 (22)	43.8 (24)	42.8 (22)
(mm)	Str.	41.6 (27)	40.4 (31)	28.8 (22)	1.5 (20)
	Grip	46.4 (26)**	42.0 (31)**	16.9 (15)**	18.8 (16)**
Dep.	Rest	7.6 (7)	5.4 (10)	12.4 (16)	8.9 (8)
(mm)	Str.	10.9 (16)	9.8 (14)	12.7 (11)	9.4 (6)
	Grip	4.7 (4)	4.1 (4)	10.6 (12)	6.4 (5)
Ang.	Rest	5.6 (5)	3.6 (3)**	6.8 (5)	7.3 (5)**
(mm)	Str.	17.9 (12)	17.8 (24)	23.1 (21)	17.2 (14)
	Grip	5.0 (4)**	4.9 (6)**	14.1 (15)**	12.5 (11)**
Bor.	Rest**	23.1 (24)	8.0 (9)**	23.5 (19)	38.4 (21)**
(mm)	Str.	9.1 (8)	13.5 (17)	9.8 (7)	8.5 (6)
**	Grip	6.6 (6)	12.1 (19)	13.3 (12)	11.9 (11)
Cha.	Rest	13.1 (14)	12.7 (20)	8.5 (9)	8.1 (7)
(mm)	Str.**	75.2 (16)	67.2 (19)	68.2 (14)	76.1 (12)
	Grip	56.6 (21)	46.7 (27)	57.4 (26)	56.1 (23)

Irr.	Rest	9.1 (13)	3.7 (4)	9.3 (11)	9.2 (10)
(mm)	Str.	29.1 (20)	27.1 (20)	39.5 (28)	36.8 (26)
	Grip	5.9 (5)**	7.5 (9)**	22.5 (20)**	26.3 (27)**

Overall significant interaction listed in left hand column (** = $p<.05$, * = $p<.10$). Simple effects test of AM/PM x MEQ interaction listed in Task column. Tukey's test compares Morning and Evening types (** = significant difference). Standard deviations listed in parentheses.

Table 9

Mean change from rest for psychological self-report variables.

		AM Session	PM Session
Anxious	Stroop	26.7 (25.9)	28.3 (18.8)
	Grip	6.3 (22.7)	6.6 (15.7)
Frustrated	Stroop	39.1 (24.9)	35.7 (21.3)
	Grip	11.6 (22.6)	9.8 (17.4)
Interested	Stroop	27.6 (27.6)	21.9 (26.3)
	Grip	.9 (24.5)	-1.9 (22.0)
Tired	Stroop	-20.4 (17.1)	-21.1 (19.5)
	Grip	-14.0 (25.3)	-11.1 (28.9)
Happy	Stroop	-8.7 (27.4)	-13.5 (20.5)
	Grip	-11.8 (25.5)	-18.9 (18.6)
Depressed	Stroop	1.9 (12.1)	2.5 (12.7)
	Grip	-2.4 (6.6)	-1.9 (8.6)
Angry	Stroop	14.2 (16.0)	12.1 (18.5)
	Grip	3.2 (11.2)	3.2 (7.7)
Bored	Stroop	-13.8 (22.3)	-11.5 (26.4)
	Grip	-13.5 (19.1)	-10.6 (27.6)
Challenged	Stroop	61.0 (19.1)	61.0 (26.0)
	Grip	46.1 (28.2)	40.7 (28.3)
Irritated	Stroop	24.9 (23.3)	25.4 (23.8)
	Grip	4.7 (19.6)	10.2 (20.3)

No significant AM/PM effects were found for change scores.
Standard deviations listed in parentheses.

Table 10

Change in self-report of psychological state by MEQ.

		Morning Subjects		Evening Subjects	
		AM	PM	AM	PM
Anxious	Stroop	24.6 (31)	25.0 (20)	29.0 (20)	31.9 (18)
(mm) *	Grip*	.8 (28)	8.6 (17)	12.3 (15)	4.5 (14)
Frustrated	Stroop	36.9 (29)	30.5 (23)	41.5 (21)	41.3 (18)
(mm) *	Grip	1.7(19)**	3.9 (15)	22.2(22)**	16.2 (18)
Interested	Stroop	32.9 (24)	24.1 (27)	21.8 (31)	19.5 (26)
(mm)	Grip	2.9 (13)	4.0 (22)	-1.2 (33)	-8.2 (21)
Tired	Stroop	-16.3 (19)	-16.1 (23)	-24.9 (14)	-26.5(14)
(mm)	Grip	-8.4 (25)	-10.6 (20)	-20.1 (25)	-11.6(37)
Happy	Stroop	-4.7 (29)	-15.6 (17)	-13.2 (26)	-11.3(24)
(mm) *	Grip*	0 (21)**	-14.0 (15)	-26(24)**	-24.1(21)
Depressed	Stroop	3.3 (14)	4.4 (16.5)	.3 (10)	.5 (7)
(mm)	Grip	-2.9 (5)	-1.2 (11)	-1.8 (8)	-2.5 (5)
Angry	Stroop	12.3 (12)	14.2 (23)	16.3 (20)	9.8 (13)
(mm)	Grip	-.6 (3)	1.4 (6)	7.3 (15)	5.2 (9)
Bored	Stroop **	-14.0 (23)	5.5(16)**	-13.6(23)	-30(23)**
(mm) **	Grip**	-16.6 (22)	4.1(19)**	-10.2 (16)	27(27)**
Challenged	Stroop **	62.1 (22)	54.5 (32)	59.7 (15)	68.0 (15)
(mm) *	Grip	43.6 (28)	34.0 (33)	48.8 (29)	48.0 (22)
Irritated	Stroop	19.9 (17)	23.4 (18)	30.2 (29)	27.6 (29)
(mm)	Grip	-3.2(12)**	3.8 (8.4)	13.2(23)**	17.1 (27)

Significant overall AM/PM x MEQ, and AM/PM x MEQ x Task interaction listed in left had column (** = p<.05, * = p<.10). Simple effects test for AM/PM by MEQ interactions listed in Task column. Tukey's test of Morning/Evening differences (** = significant). Standard deviations listed in parentheses.

Table 11

Summary of Results

	Physiological Variables	Psychological Variables	Performance Variables
AM/PM Circadian Differences	***Responses greater in the PM*** SBP, DBP, HR	***Responses greater in the AM*** Frustrated	***Performance better in the PM*** CPT omissions
AM/PM and MEQ Interactions	***Morning type responds more in the AM*** ***Evening type responds more in the PM*** RPP, SBP	***Morning type responds more in the AM*** ***Evening type responds more in the PM*** Bored	NONE
MEQ Differences Morning vs. Evening Types	NONE	***Evening type is higher in negative affect*** Frustrated Tired Irritated Bored	***Evening type performs better*** Stroop # trials # correct response window

All variables listed were significant at the $p<.05$ level. SBP = systolic blood pressure, DBP = diastolic blood pressure, HR = heart rate, RPP = rate pressure product.

Figure 1. Model of circadian phase.

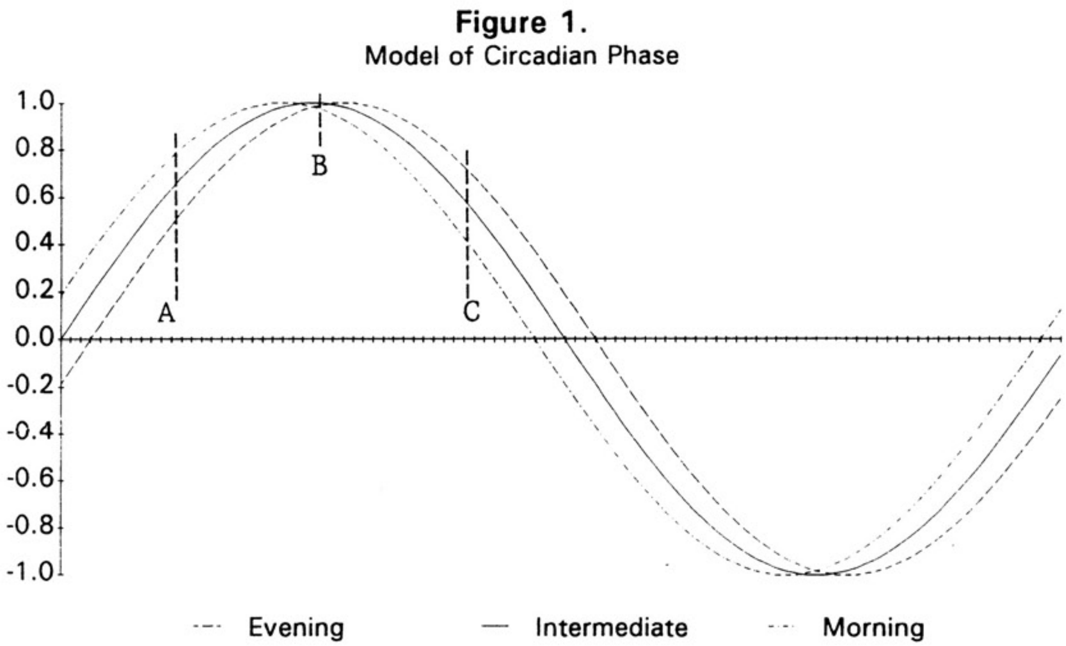


Figure 2. Interaction between circadian type (Morning vs. Evening) and time of day for cardiovascular levels in healthy subjects. Lines do not represent continuous data.

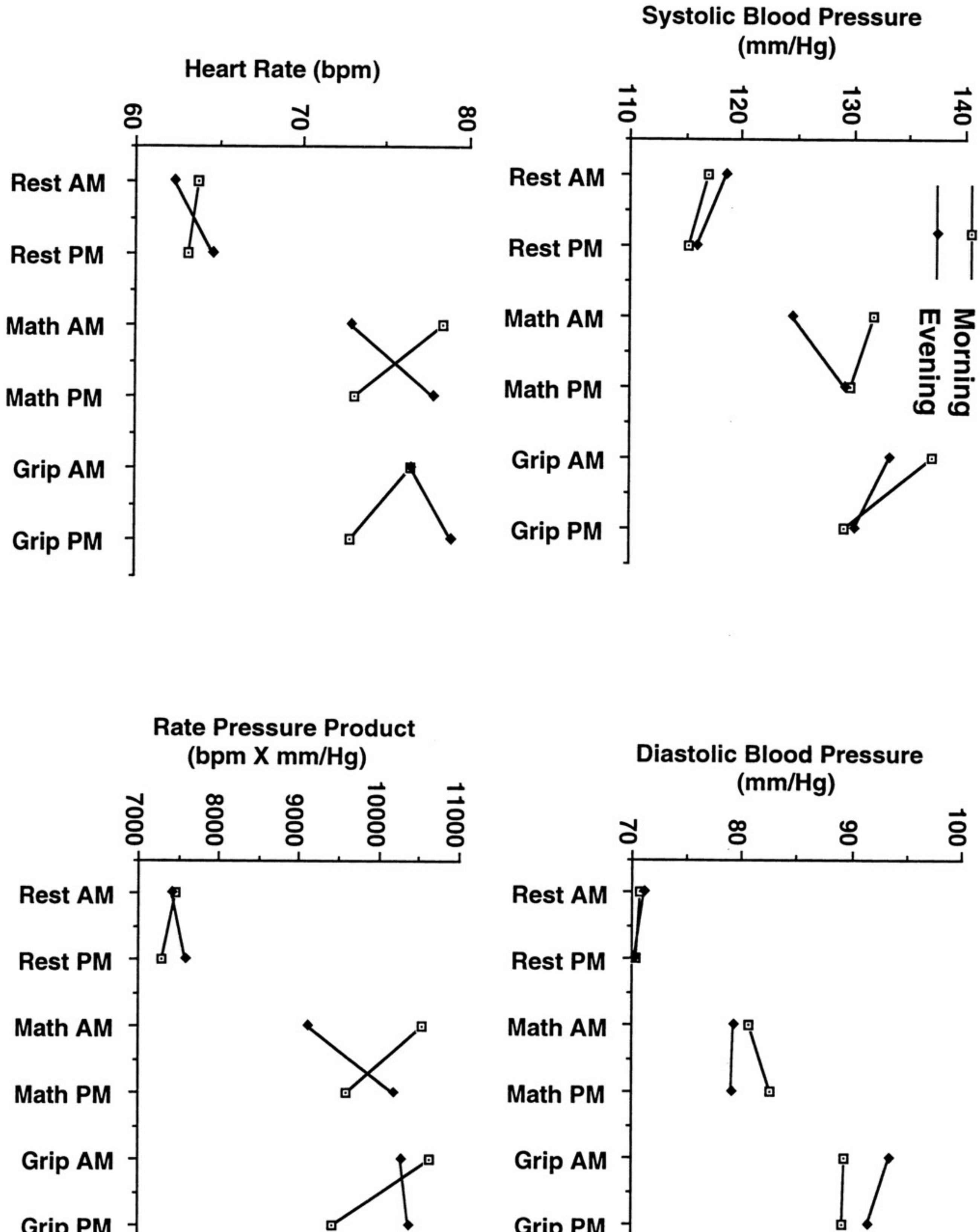

Systolic Blood Pressure (mm/Hg)
110
120
130
140
Morning
Evening
Heart Rate (bpm)
60
70
80
Diastolic Blood Pressure (mm/Hg)
70
80
90
100
Rate Pressure Product (bpm X mm/Hg)
7000
8000
9000
10000
11000
Rest AM
Rest PM
Math AM
Math PM
Grip AM
Grip PM

Figure 3. Interaction between circadian type (Morning vs. Evening) and time of day for cardiovascular change scores (task minus resting levels) in healthy subjects. Lines do not represent continuous data.

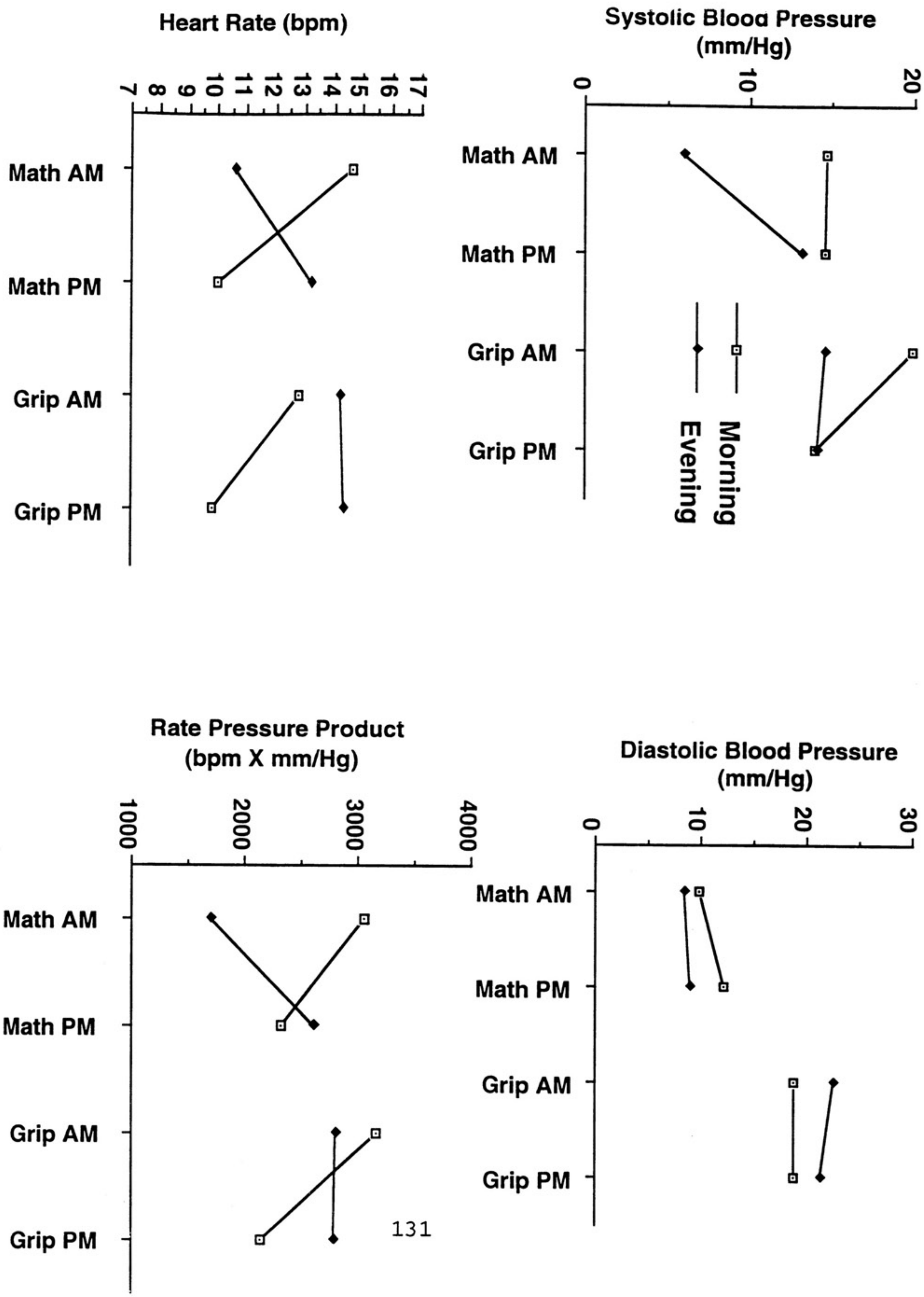
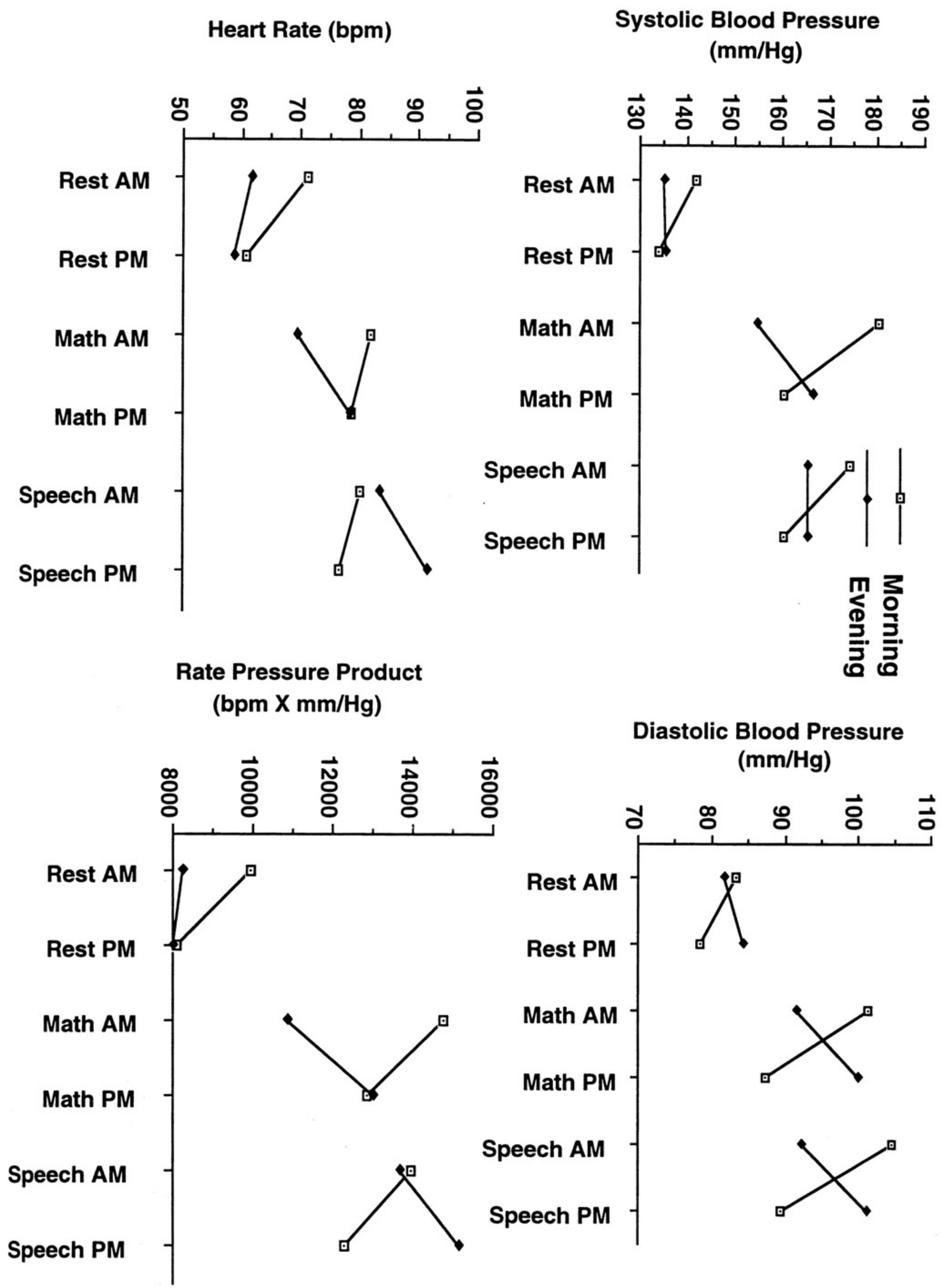

Systolic Blood Pressure
(mm/Hg)
0
10
20
Math AM
Math PM
Grip AM
Grip PM
Morning
Evening
Heart Rate (bpm)
7
8
9
10
11
12
13
14
15
16
17
Math AM
Math PM
Grip AM
Grip PM
Diastolic Blood Pressure
(mm/Hg)
0
10
20
30
Math AM
Math PM
Grip AM
Grip PM
Rate Pressure Product
(bpm X mm/Hg)
1000
2000
3000
4000
Math AM
Math PM
Grip AM
Grip PM

Figure 4. Interaction between circadian type (Morning vs. Evening) and time of day for cardiovascular levels in CAD subjects. Lines do not represent continuous data.



Systolic Blood Pressure (mm/Hg)
130
140
150
160
170
180
190
Rest AM
Rest PM
Math AM
Math PM
Speech AM
Speech PM
Morning
Evening
Heart Rate (bpm)
50
60
70
80
90
100
Rest AM
Rest PM
Math AM
Math PM
Speech AM
Speech PM
Diastolic Blood Pressure (mm/Hg)
70
80
90
100
110
Rest AM
Rest PM
Math AM
Math PM
Speech AM
Speech PM
Rate Pressure Product (bpm X mm/Hg)
8000
10000
12000
14000
16000
Rest AM
Rest PM
Math AM
Math PM
Speech AM
Speech PM

Figure 5. Interaction between circadian type (Morning vs. Evening) and time of day for cardiovascular change scores (task minus resting levels) in CAD subjects. Lines do not represent continuous data.

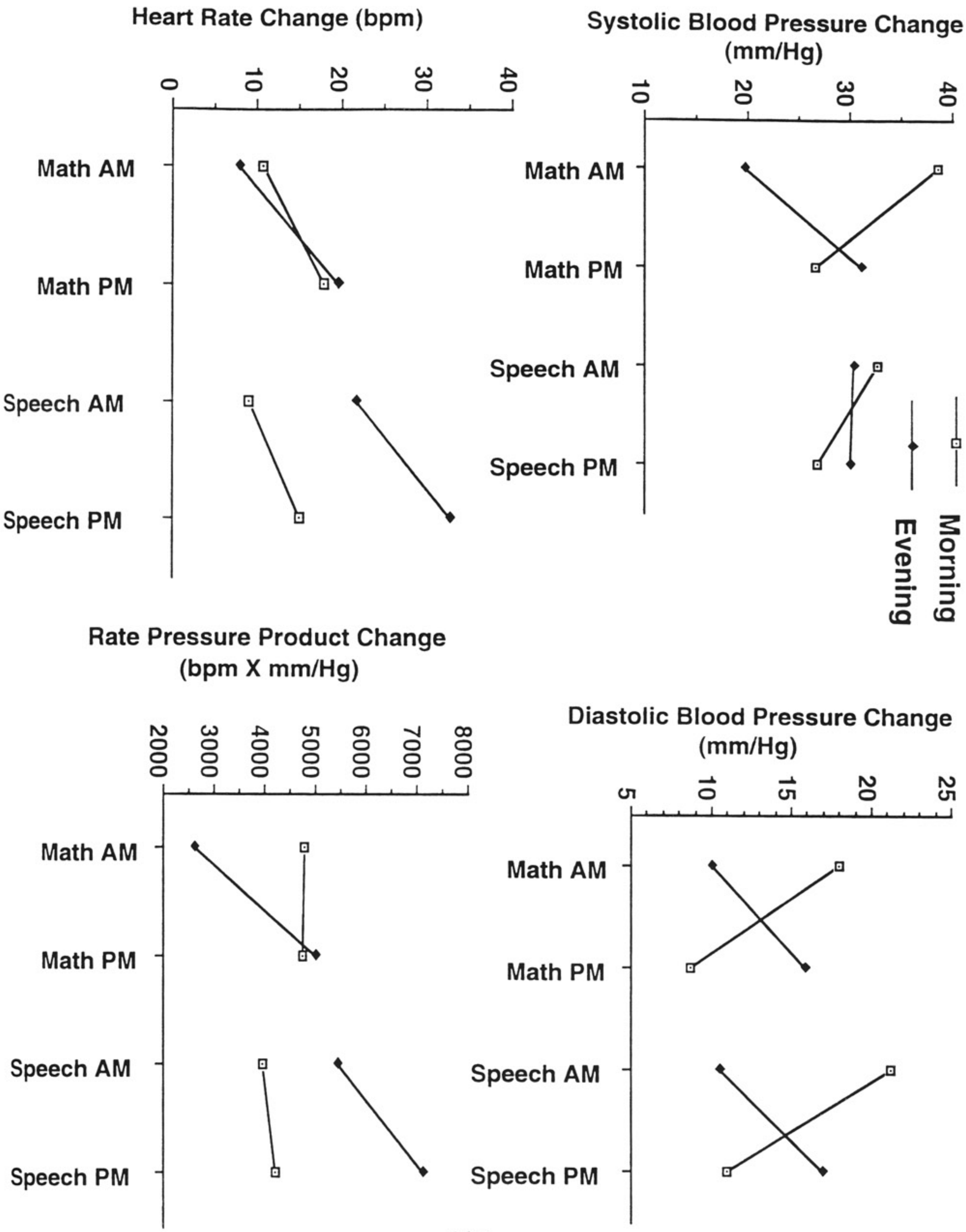
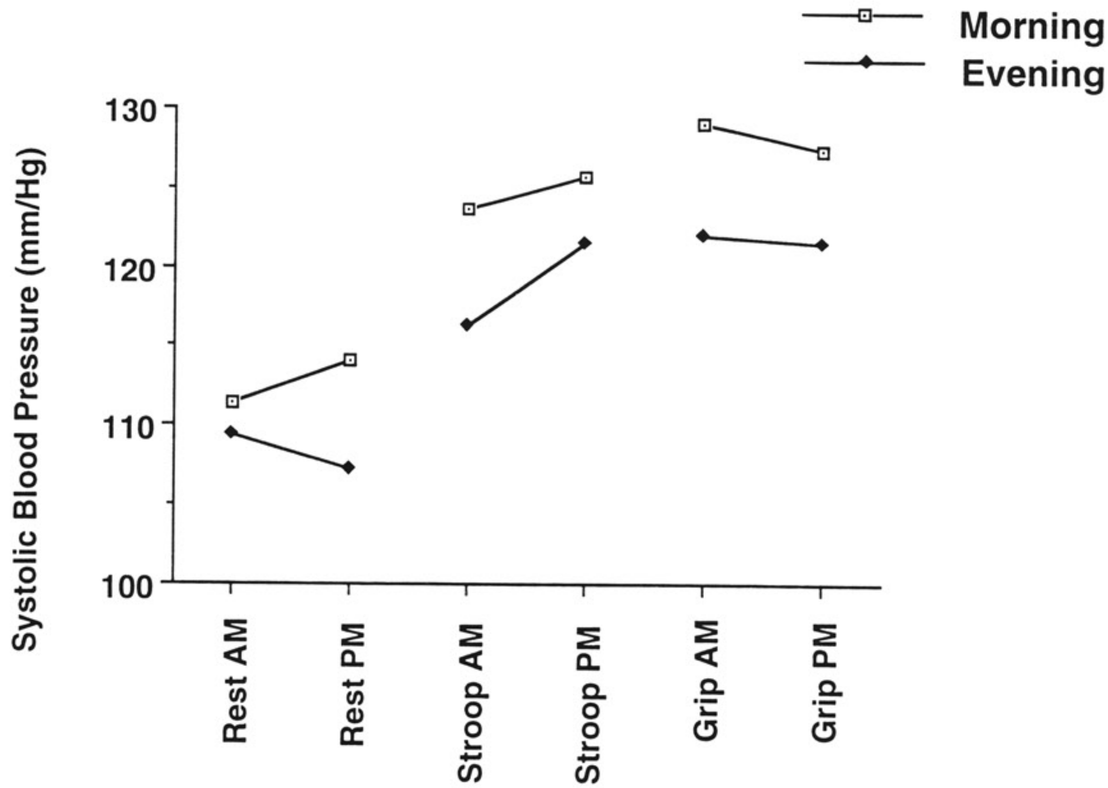

Heart Rate Change (bpm)
0
10
20
30
40
Math AM
Math PM
Speech AM
Speech PM
Systolic Blood Pressure Change (mm/Hg)
10
20
30
40
Math AM
Math PM
Speech AM
Speech PM
Morning
Evening
Rate Pressure Product Change (bpm X mm/Hg)
2000
3000
4000
5000
6000
7000
8000
Math AM
Math PM
Speech AM
Speech PM
Diastolic Blood Pressure Change (mm/Hg)
5
10
15
20
25
Math AM
Math PM
Speech AM
Speech PM

Figure 6. Interaction between circadian type (Morning vs. Evening) and time of day for systolic blood pressure levels (top) and diastolic blood pressure levels (bottom). Lines do not represent continuous data.


Morning
Evening
Systolic Blood Pressure (mm/Hg)
130
120
110
100
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM

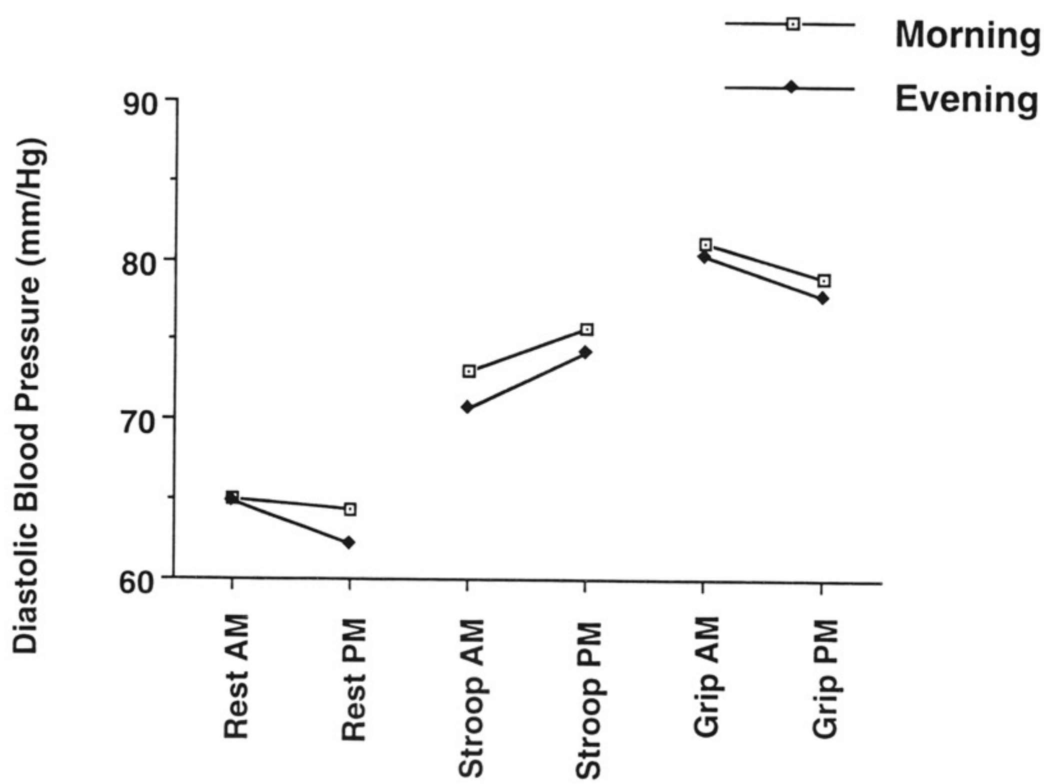
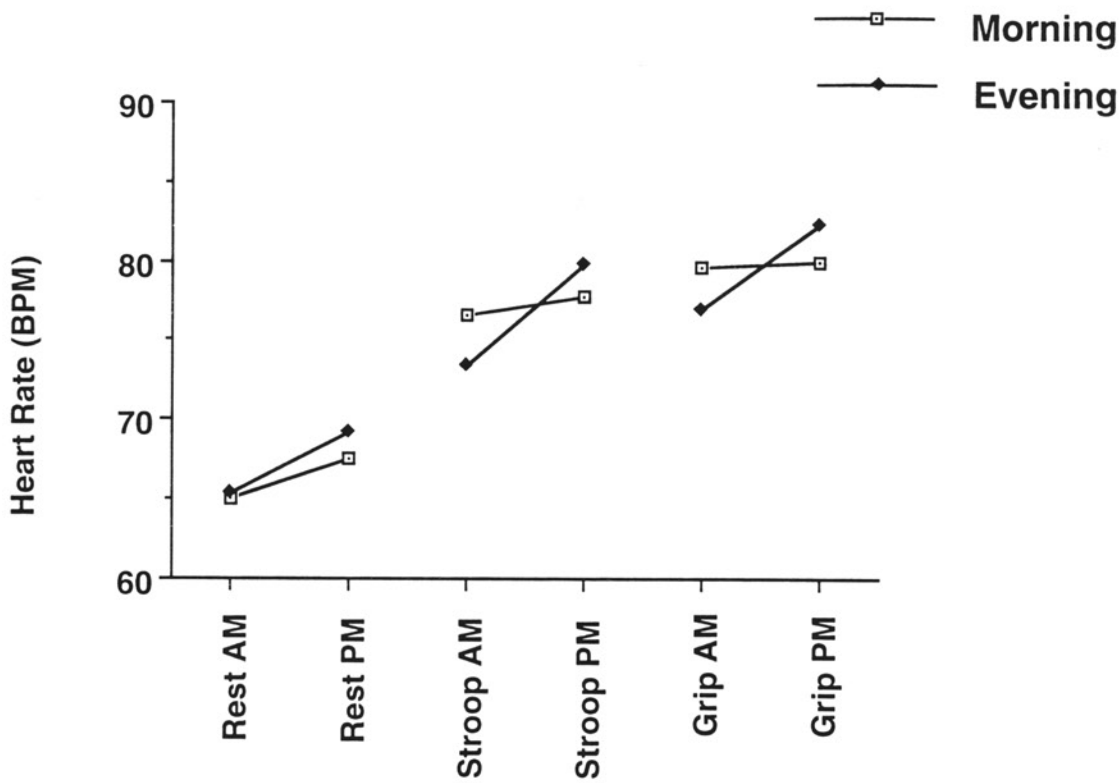
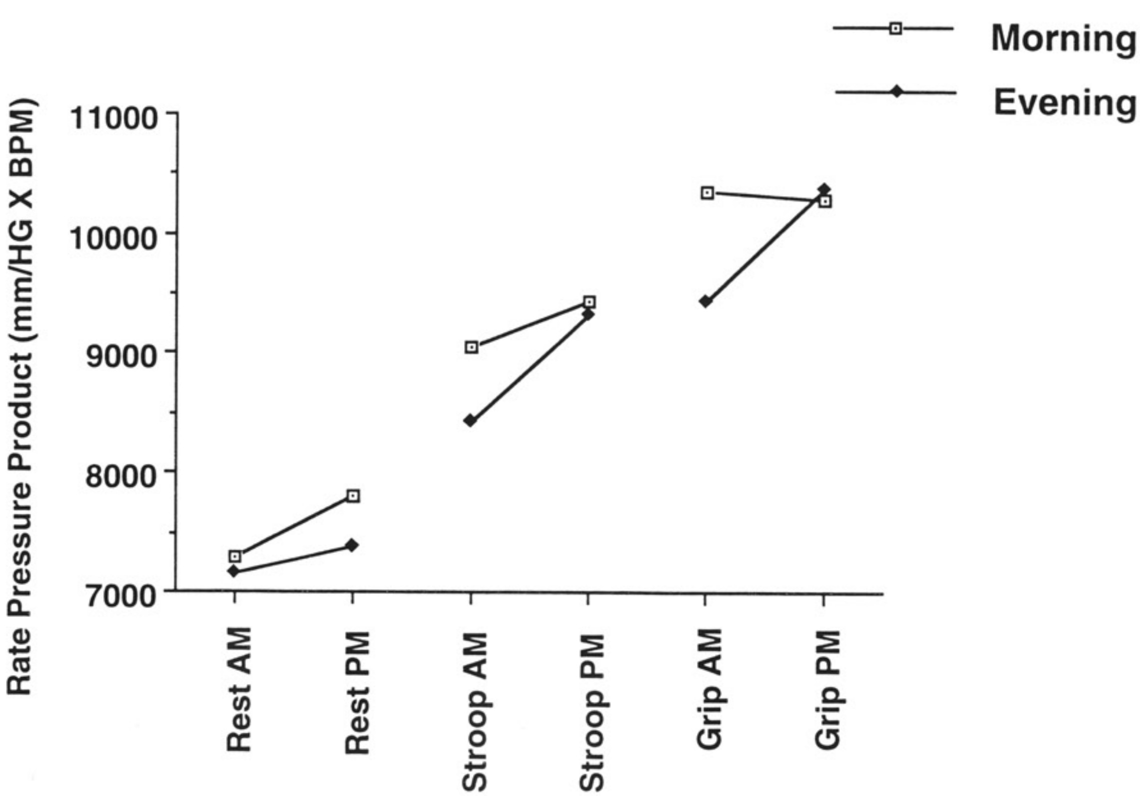

Morning
Evening
Diastolic Blood Pressure (mm/Hg)
90
80
70
60
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 7. Interaction between circadian type (Morning vs. Evening) and time of day for heart rate levels (top) and rate pressure product levels (bottom). Lines do not represent contnuous data.

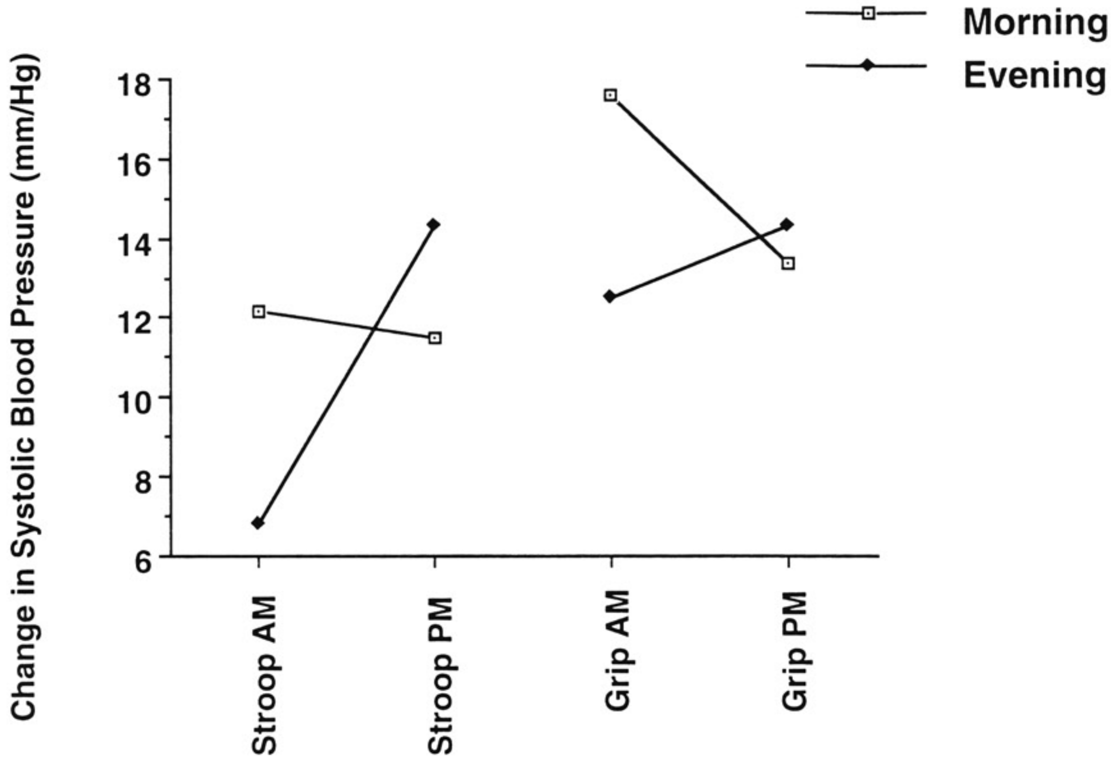


Morning
Evening
Heart Rate (BPM)
90
80
70
60
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM



Morning
Evening
Rate Pressure Product (mm/HG X BPM)
11000
10000
9000
8000
7000
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 8. Interaction between circadian type (Morning vs. Evening) and time of day for change scores (task minus rest) of systolic blood pressure (top) and diastolic blood pressure (bottom). Lines do not represent continuous data.


Morning
Evening
Change in Systolic Blood Pressure (mm/Hg)
18
16
14
12
10
8
6
Stroop AM
Stroop PM
Grip AM
Grip PM

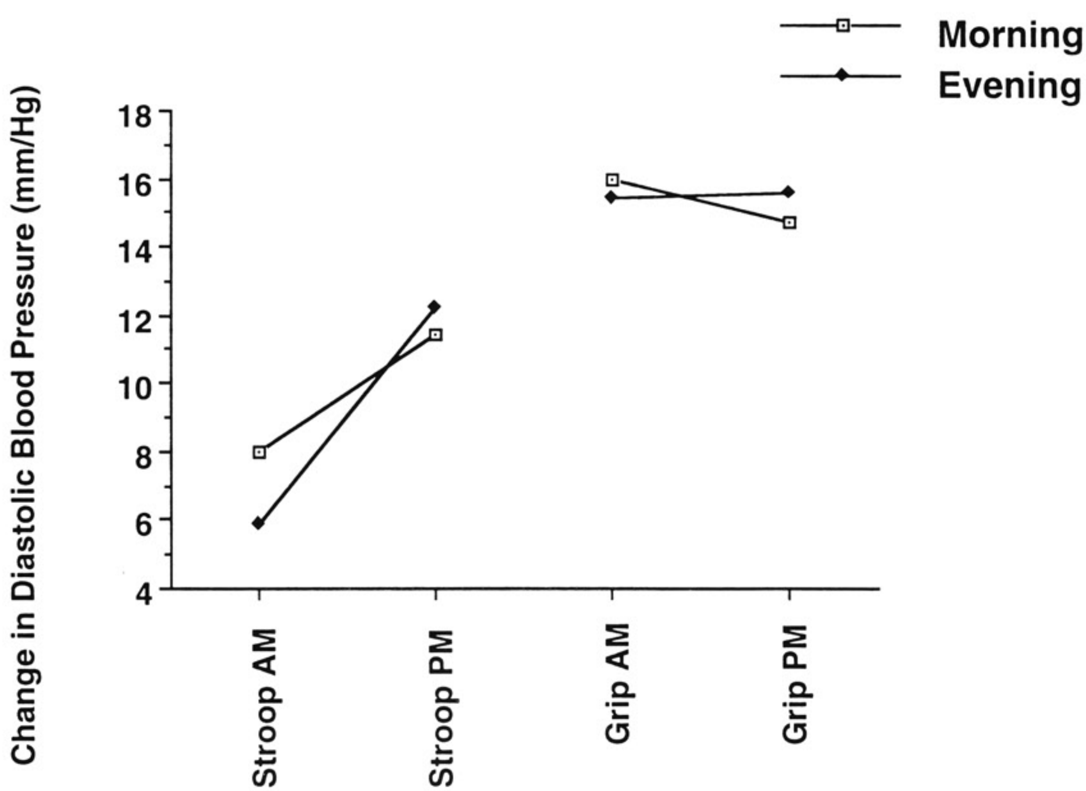
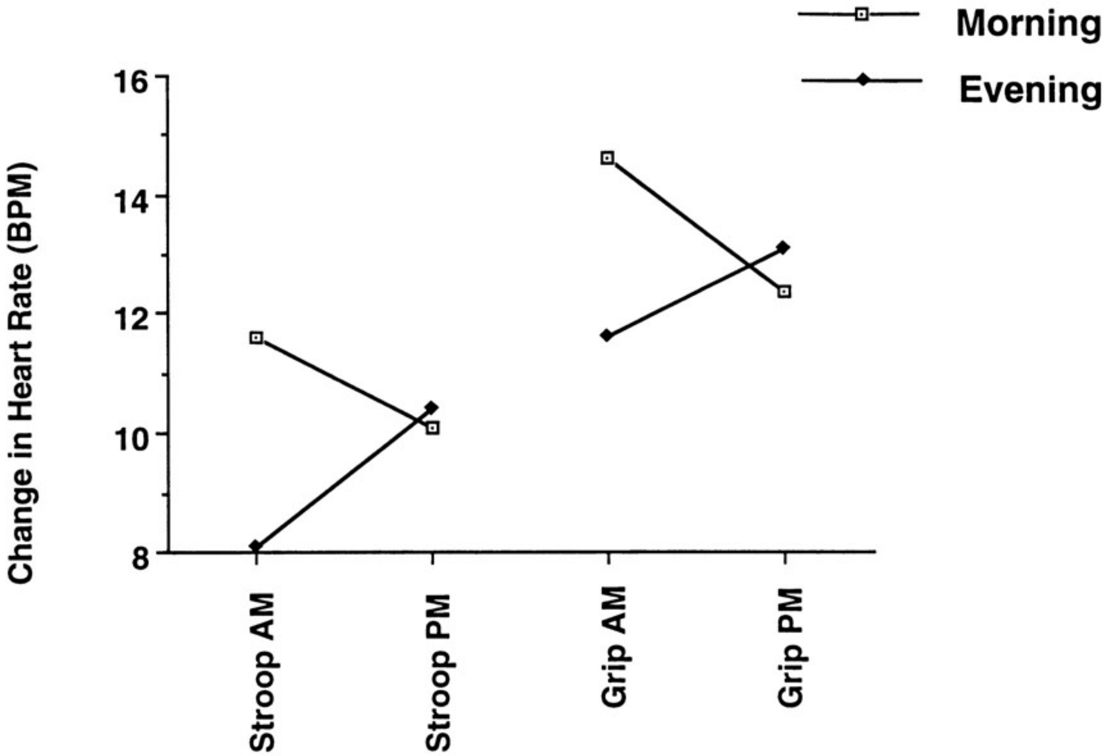

Morning
Evening
Change in Diastolic Blood Pressure (mm/Hg)
18
16
14
12
10
8
6
4
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 9. Interaction between circadian type (Morning vs. Evening) and time of day for change scores (task minus rest) of heart rate (top) and rate pressure product (bottom). Lines do not represent continuous data.


Morning
Evening
Change in Heart Rate (BPM)
16
14
12
10
8
Stroop AM
Stroop PM
Grip AM
Grip PM

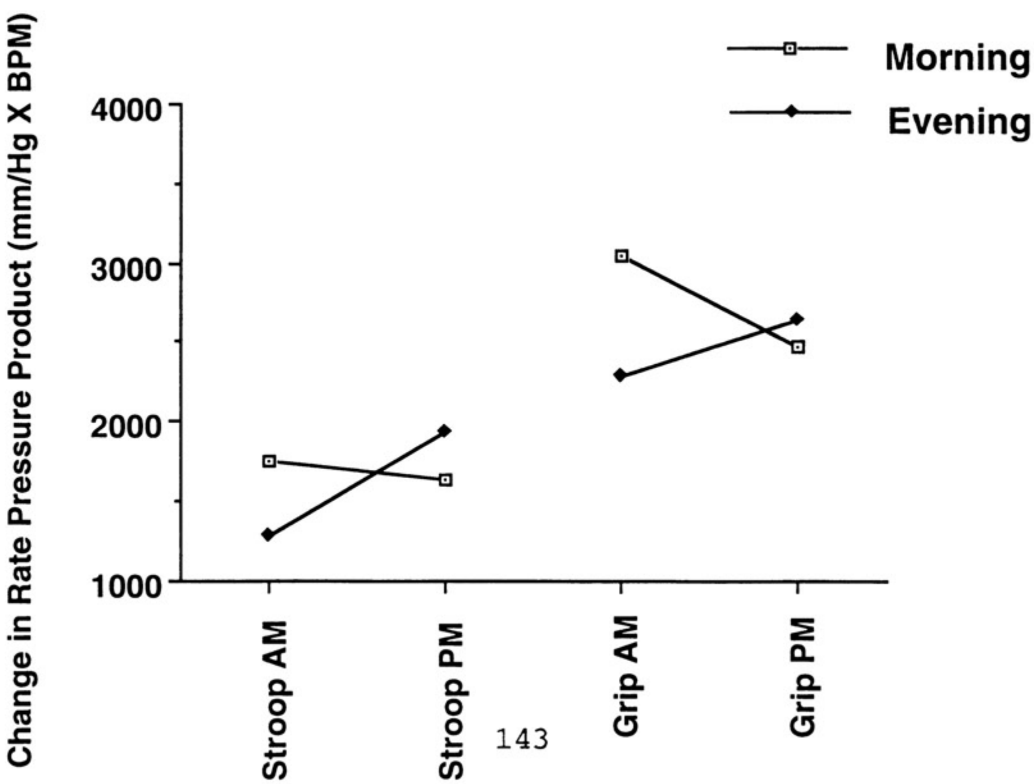
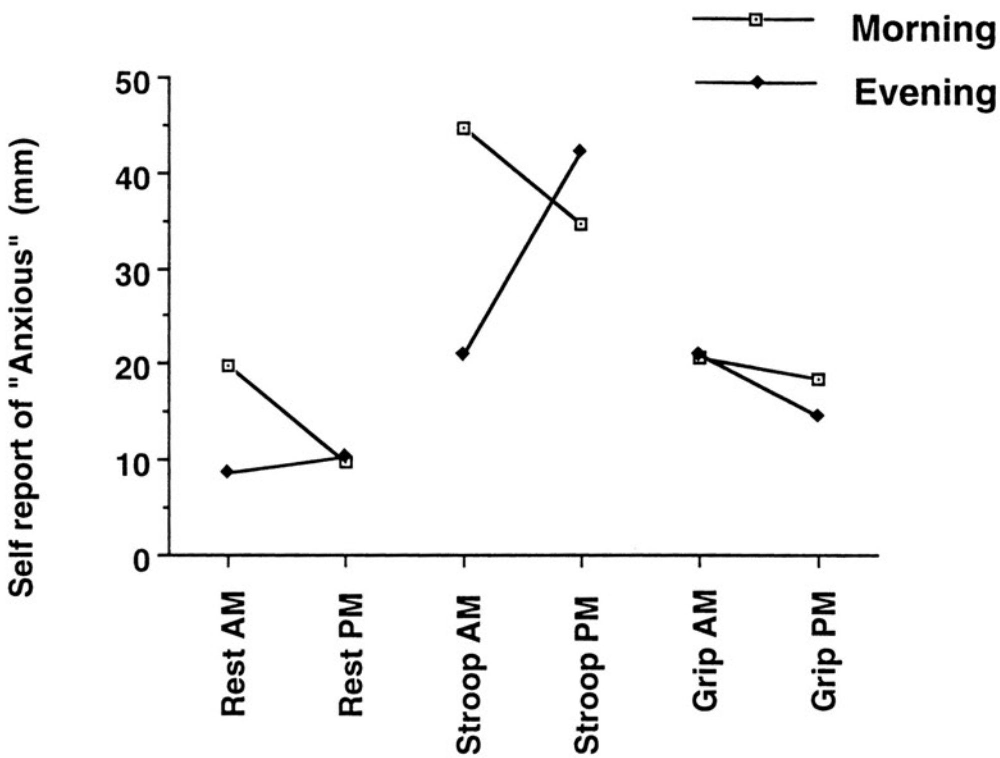
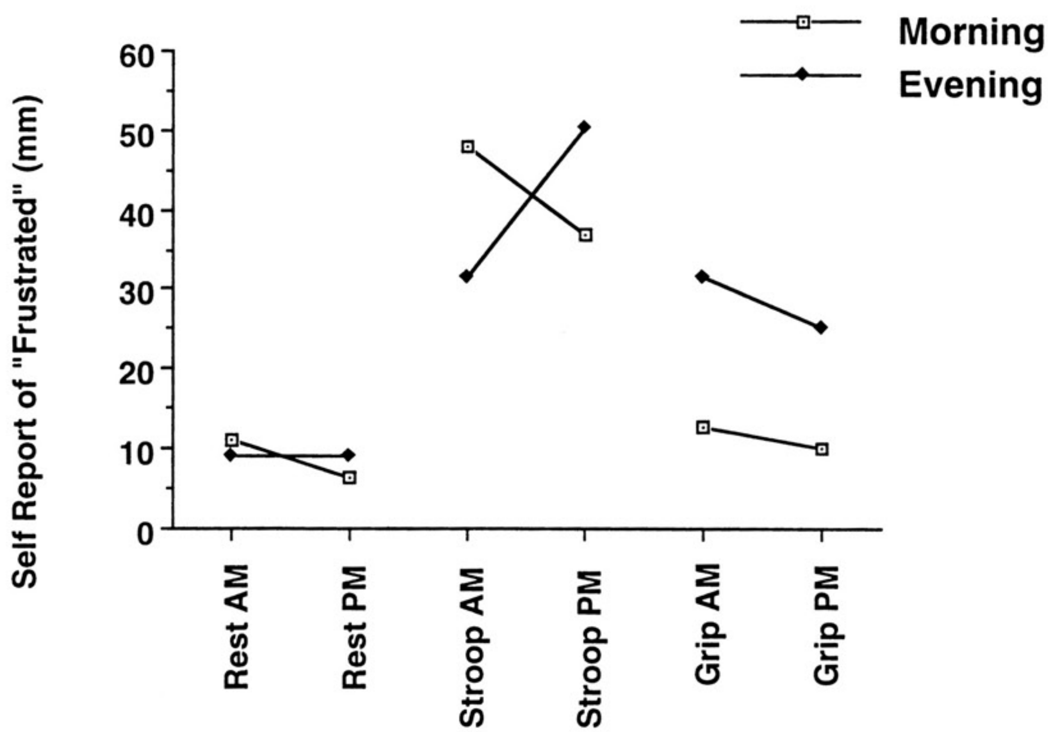

Morning
Evening
Change in Rate Pressure Product (mm/Hg X BPM)
4000
3000
2000
1000
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 10. Interaction between circadian type (Morning vs. Evening) and time of day for levels of "anxious" (top) and "frustrated" (bottom). Lines do not represent continuous data.

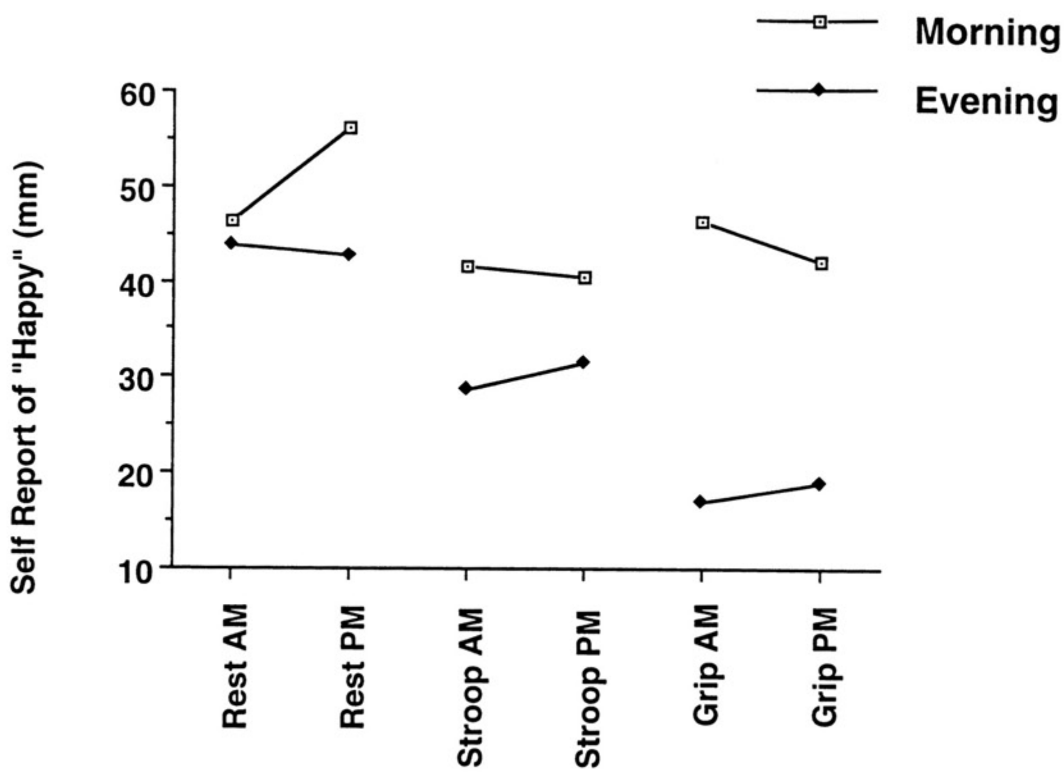


Morning
Evening
Self report of "Anxious" (mm)
50
40
30
20
10
0
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM



Morning
Evening
Self Report of "Frustrated" (mm)
60
50
40
30
20
10
0
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 11. Interaction between circadian type (Morning vs. Evening) and time of day for levels of "happy" (top) and "depressed" (bottom). Lines do not represent continuous data.


Morning
Evening
Self Report of "Happy" (mm)
60
50
40
30
20
10
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM

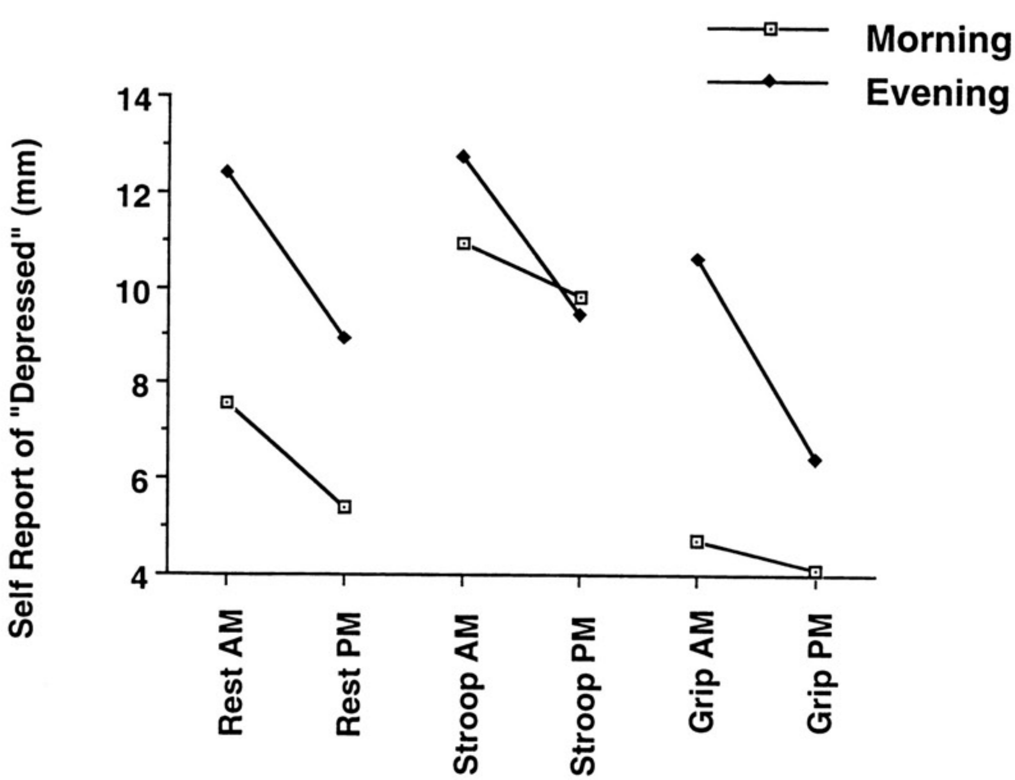
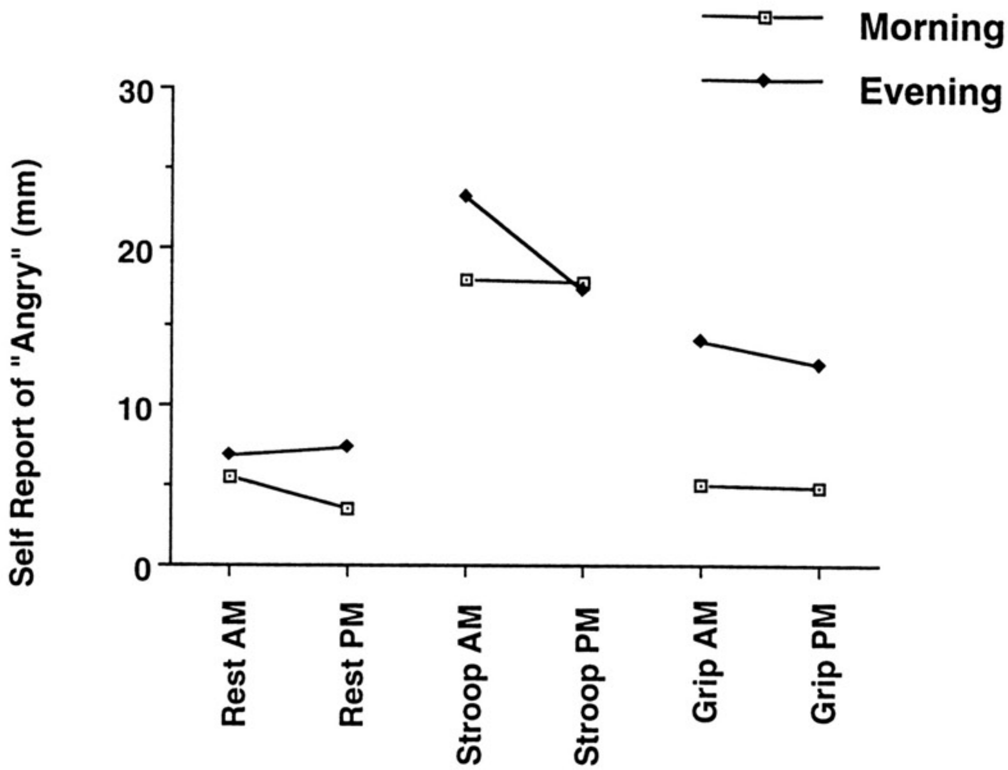

Morning
Evening
Self Report of "Depressed" (mm)
14
12
10
8
6
4
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 12. Interaction between circadian type (Morning vs. Evening) and time of day for levels of "angry" (top) and "bored" (bottom). Lines do not represent continuous data.


Morning
Evening
Self Report of "Angry" (mm)
30
20
10
0
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM

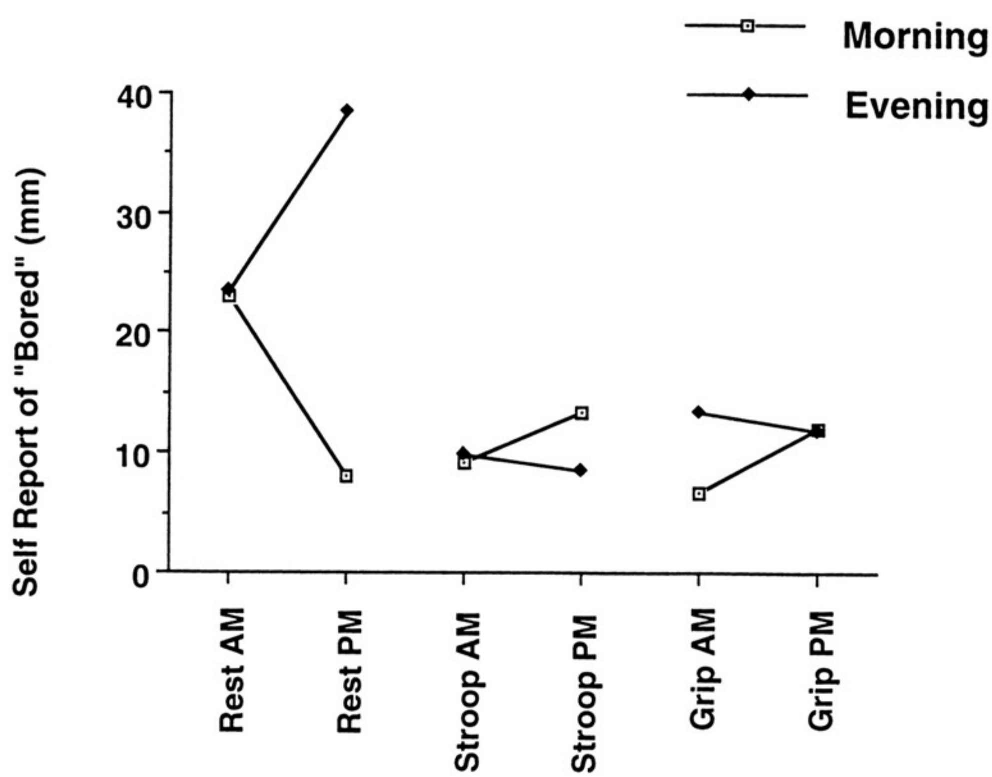
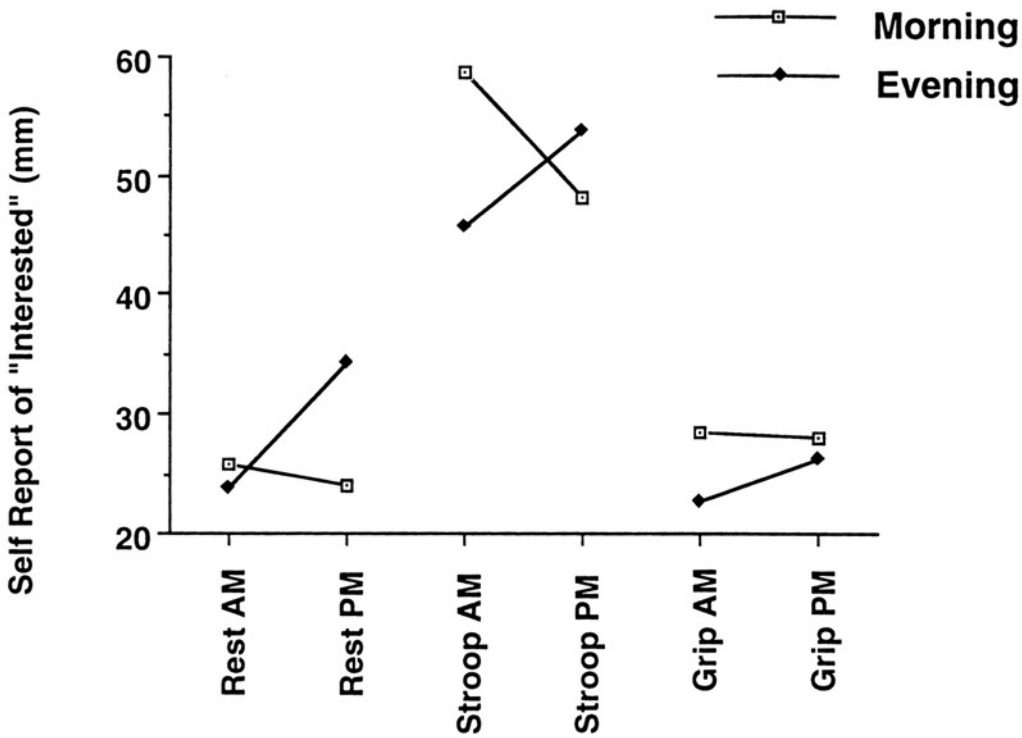

Morning
Evening
Self Report of "Bored" (mm)
40
30
20
10
0
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 13. Interaction between circadian type (Morning vs. Evening) and time of day for levels of "interested" (top) and "tired" (bottom). Lines do not represent continuous data.


Morning
Evening
Self Report of "Interested" (mm)
60
50
40
30
20
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM

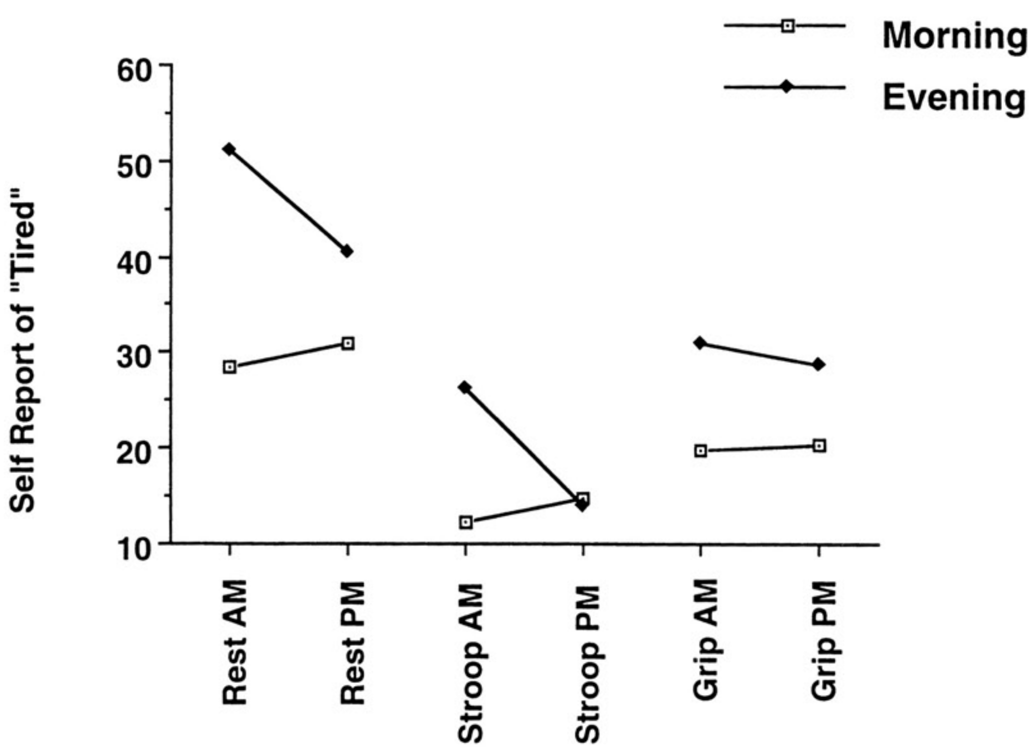
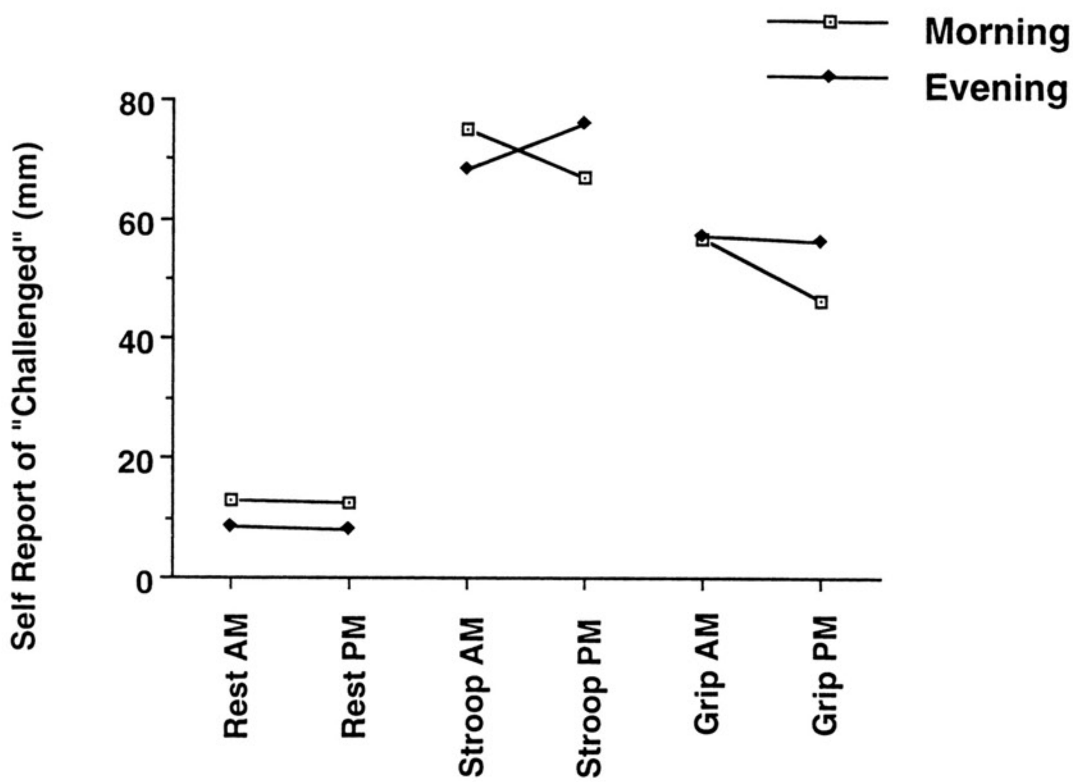
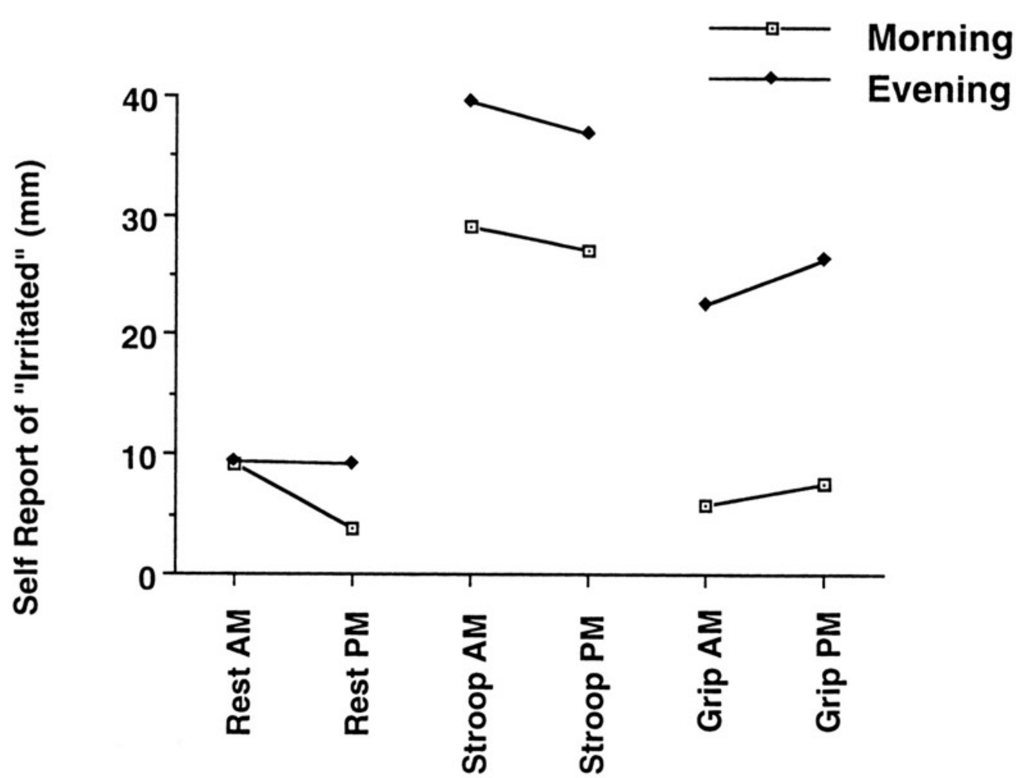

Morning
Evening
Self Report of "Tired"
60
50
40
30
20
10
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 14. Interaction between circadian type (Morning vs. Evening) and time of day for levels of "challenged" (top) and "irritated" (bottom). Lines do not represent continuous data.

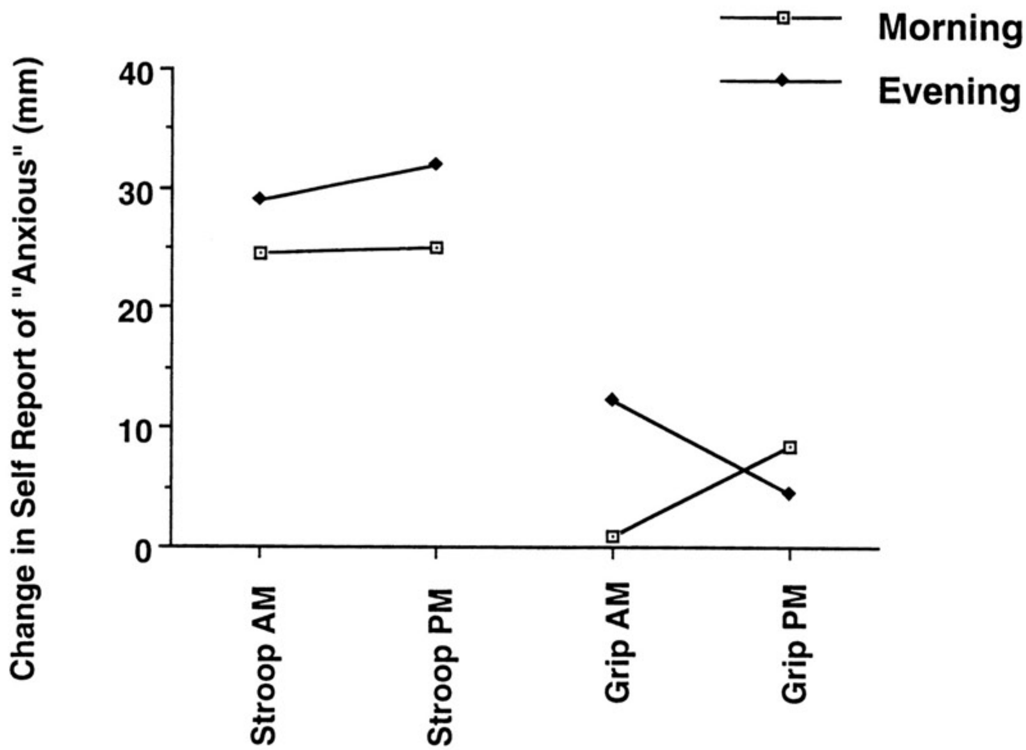


Morning
Evening
Self Report of "Challenged" (mm)
80
60
40
20
0
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM



Morning
Evening
Self Report of "Irritated" (mm)
40
30
20
10
0
Rest AM
Rest PM
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 15. Interaction between circadian type (Morning vs. Evening) and time of day for change scores (task minus rest) of "anxious" (top) and "frustrated" (bottom). Lines do not represent continuous data.


Morning
Evening
Change in Self Report of "Anxious" (mm)
40
30
20
10
0
Stroop AM
Stroop PM
Grip AM
Grip PM

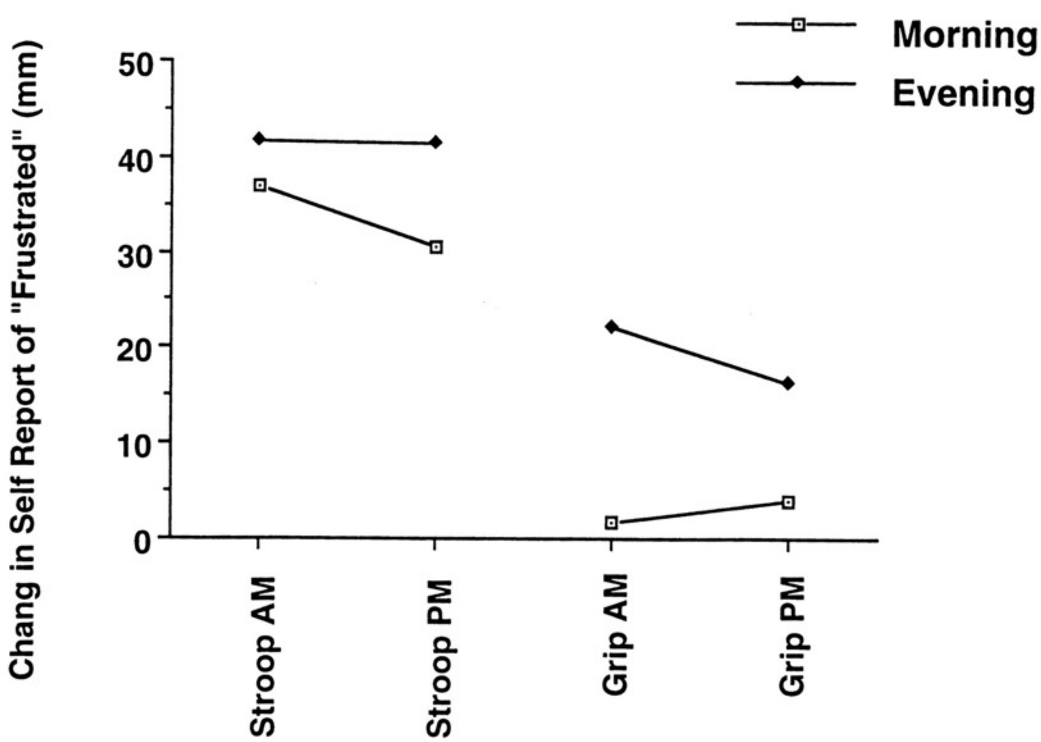
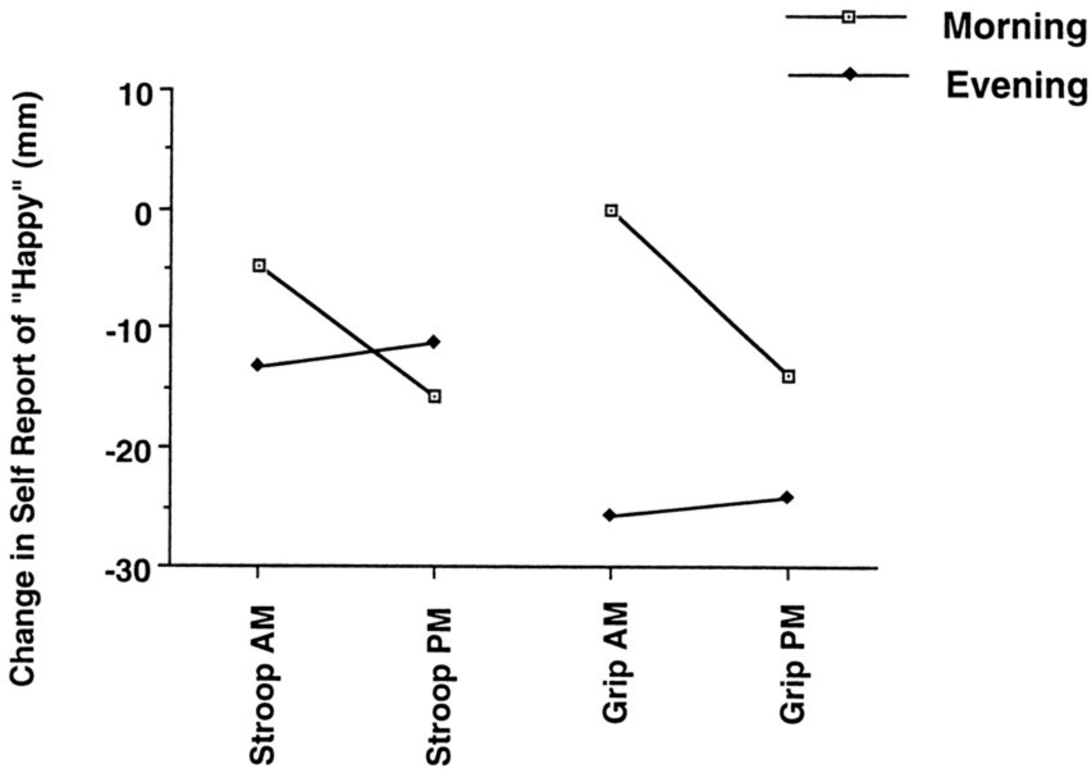

Morning
Evening
Chang in Self Report of "Frustrated" (mm)
50
40
30
20
10
0
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 16. Interaction between circadian type (Morning vs. Evening) and time of day for change scores (task minus rest) of "happy" (top) and "depressed" (bottom). Lines do not represent continuous data.


Morning
Evening
10
0
-10
-20
-30
Change in Self Report of "Happy" (mm)
Stroop AM
Stroop PM
Grip AM
Grip PM

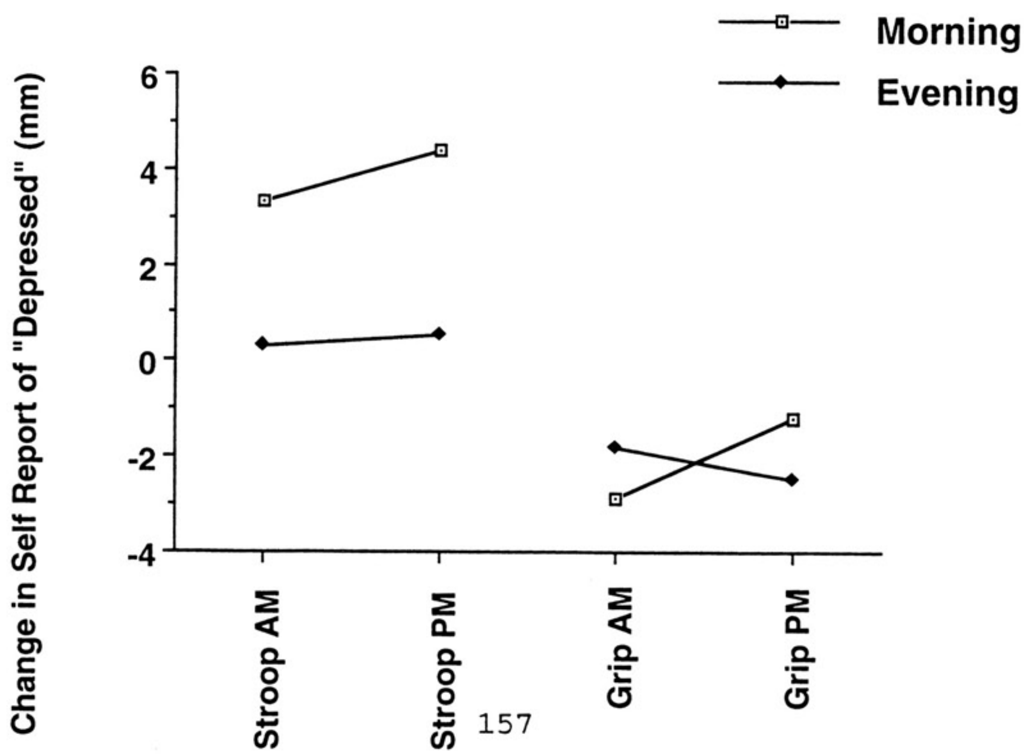
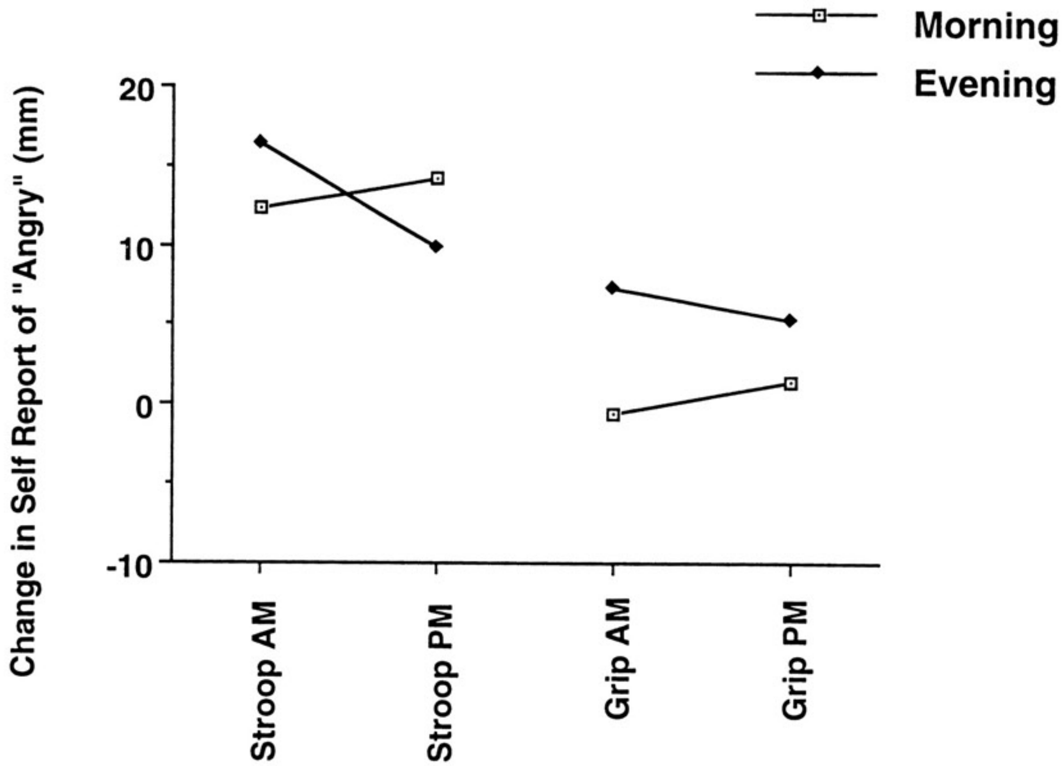

Morning
Evening
6
4
2
0
-2
-4
Change in Self Report of "Depressed" (mm)
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 17. Interaction between circadian type (Morning vs. Evening) and time of day for change scores (task minus rest) of "angry" (top) and "bored" (bottom). Lines do not represent continuous data.


Morning
Evening
Change in Self Report of "Angry" (mm)
20
10
0
-10
Stroop AM
Stroop PM
Grip AM
Grip PM

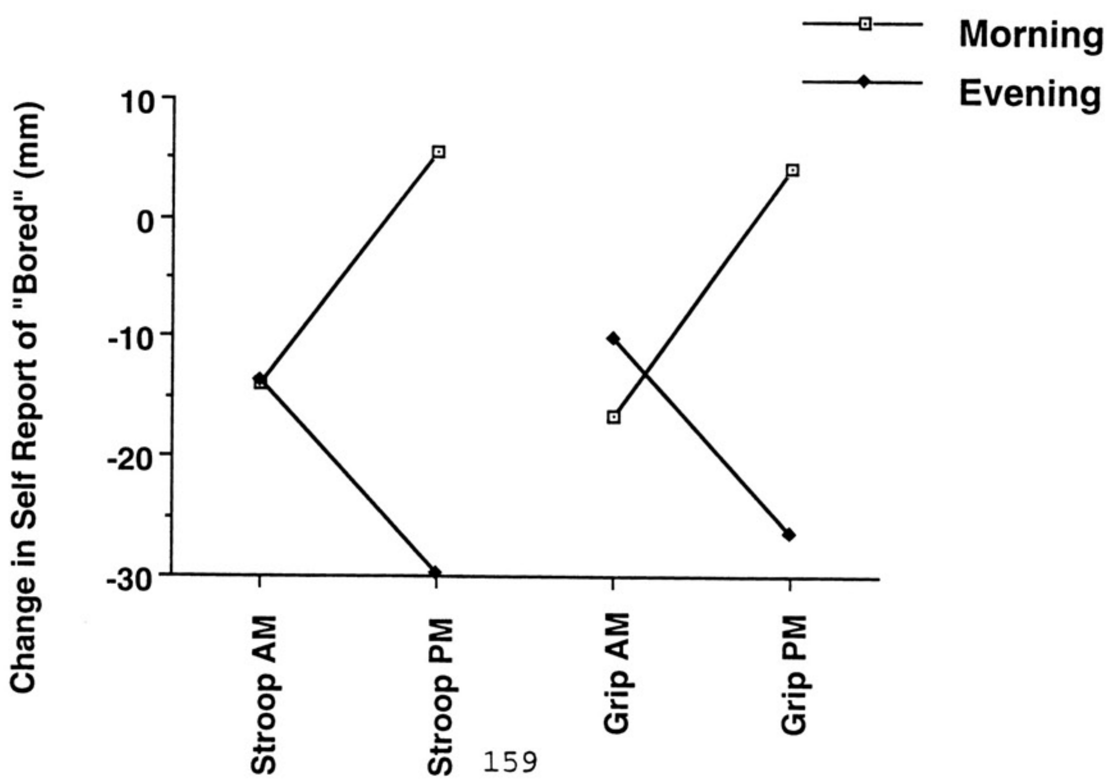
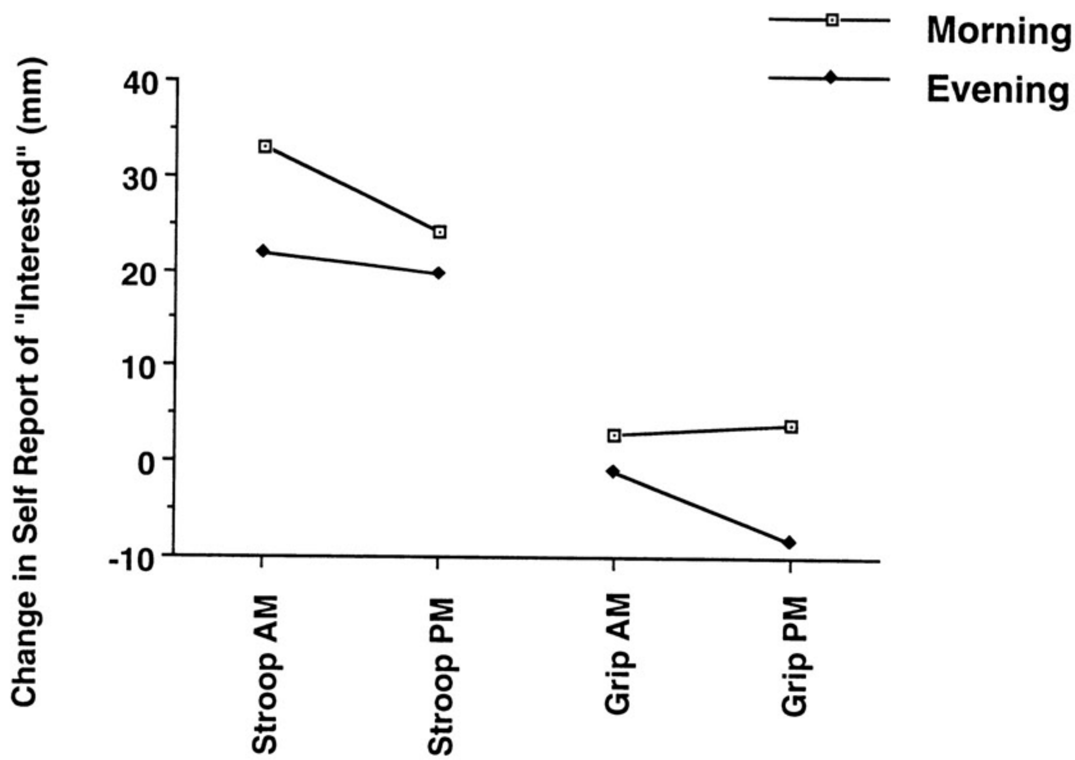

Morning
Evening
Change in Self Report of "Bored" (mm)
10
0
-10
-20
-30
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 18. Interaction between circadian type (Morning vs. Evening) and time of day for change scores (task minus rest) of "interested" (top) and "tired" (bottom). Lines do not represent continuous data.


Morning
Evening
Change in Self Report of "Interested" (mm)
40
30
20
10
0
-10
Stroop AM
Stroop PM
Grip AM
Grip PM

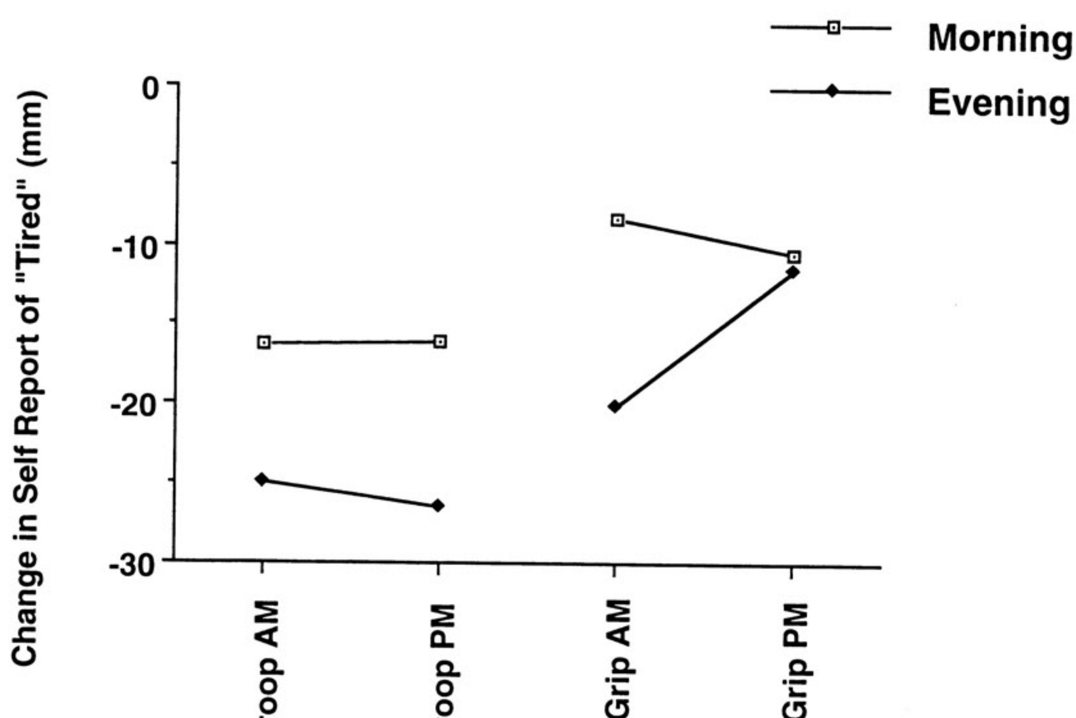
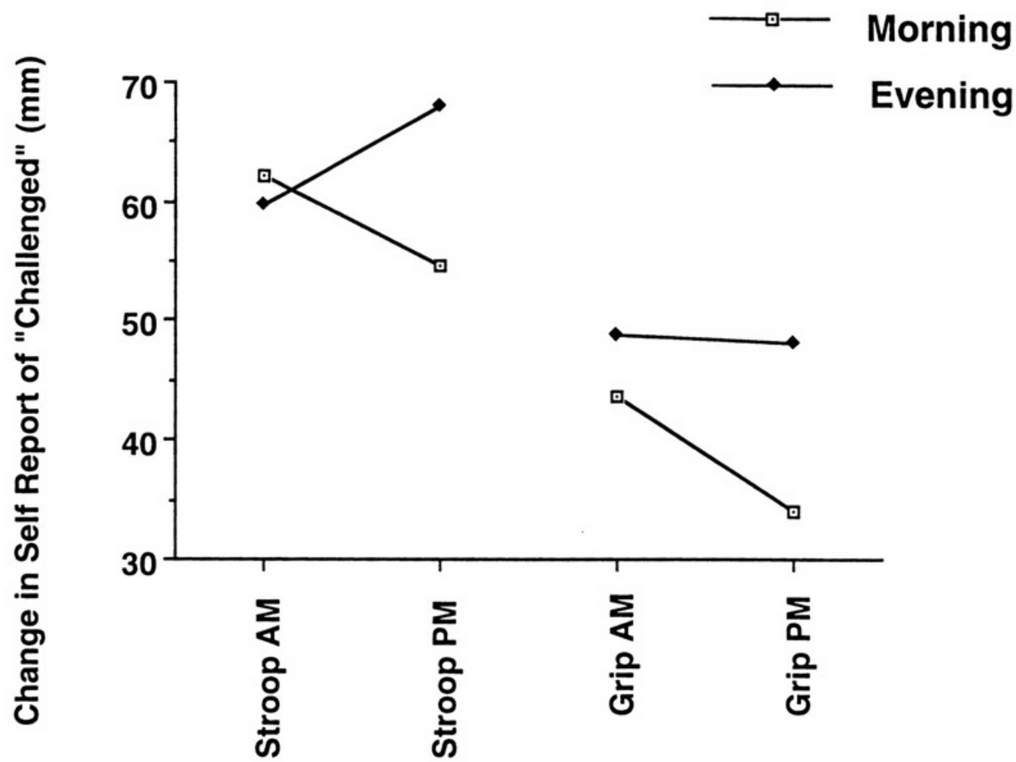

Morning
Evening
Change in Self Report of "Tired" (mm)
0
-10
-20
-30
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 19. Interaction between circadian type (Morning vs. Evening) and time of day for change scores (task minus rest) of "challenged" (top) and "irritated" (bottom). Lines do not represent continuous data.


Morning
Evening
Change in Self Report of "Challenged" (mm)
70
60
50
40
30
Stroop AM
Stroop PM
Grip AM
Grip PM

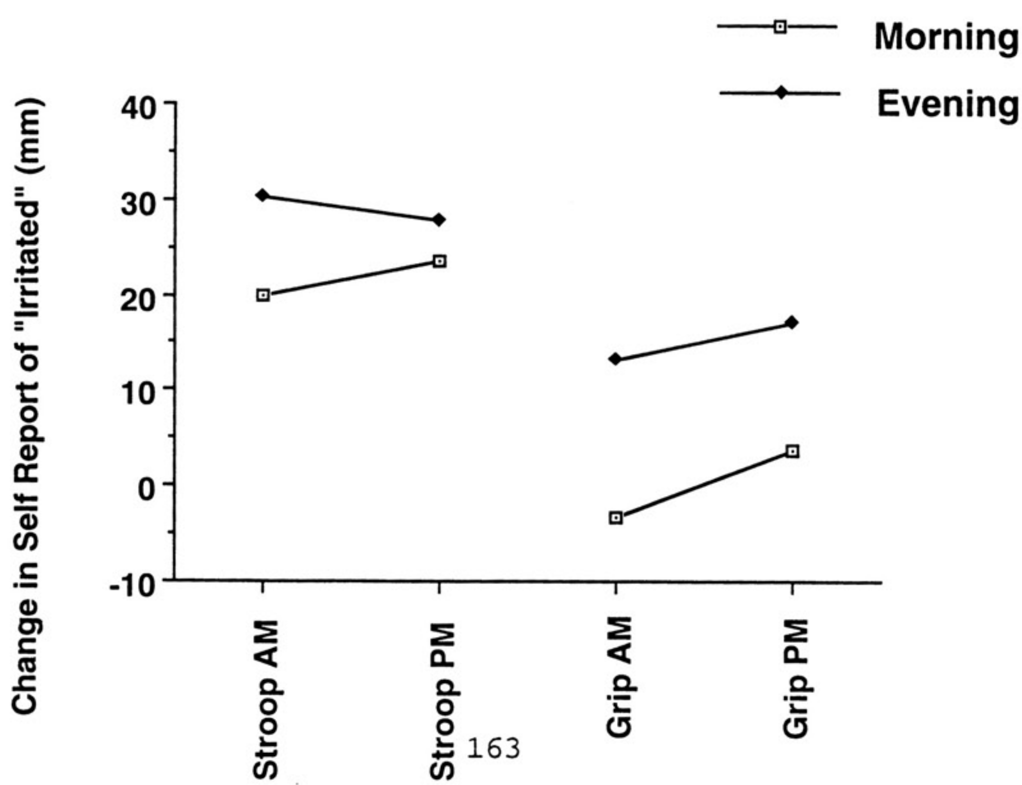
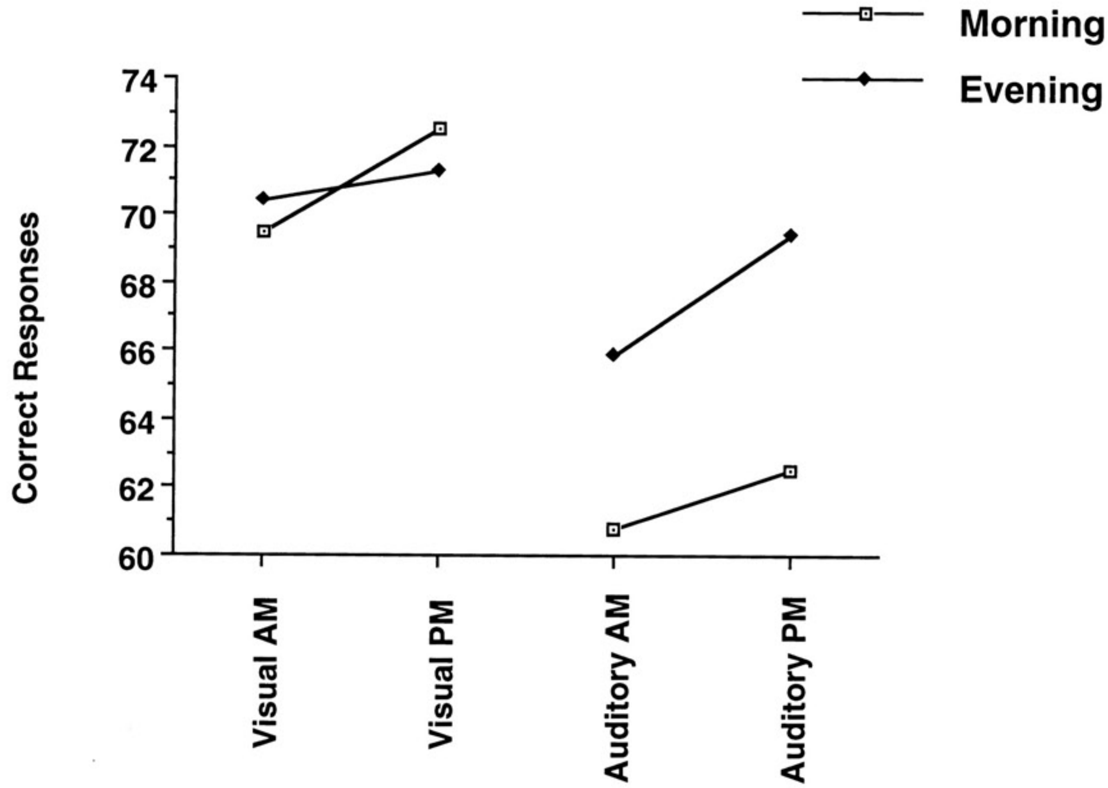

Morning
Evening
Change in Self Report of "Irritated" (mm)
40
30
20
10
0
-10
Stroop AM
Stroop PM
Grip AM
Grip PM

Figure 20. Interaction between circadian type (Morning vs. Evening) and time of day for Continuous Performance Test, number of correct responses (top) and incorrect responses (bottom). Lines do not represent continuous data.


Morning
Evening
74
72
70
68
66
64
62
60
Correct Responses
Visual AM
Visual PM
Auditory AM
Auditory PM

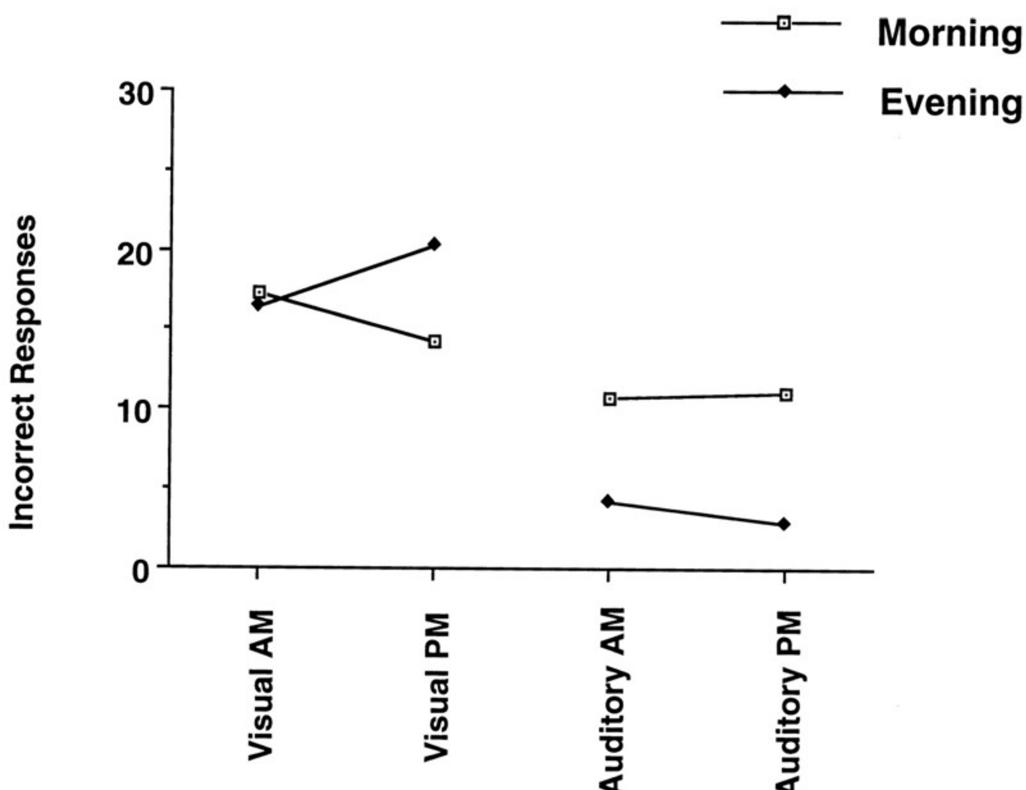
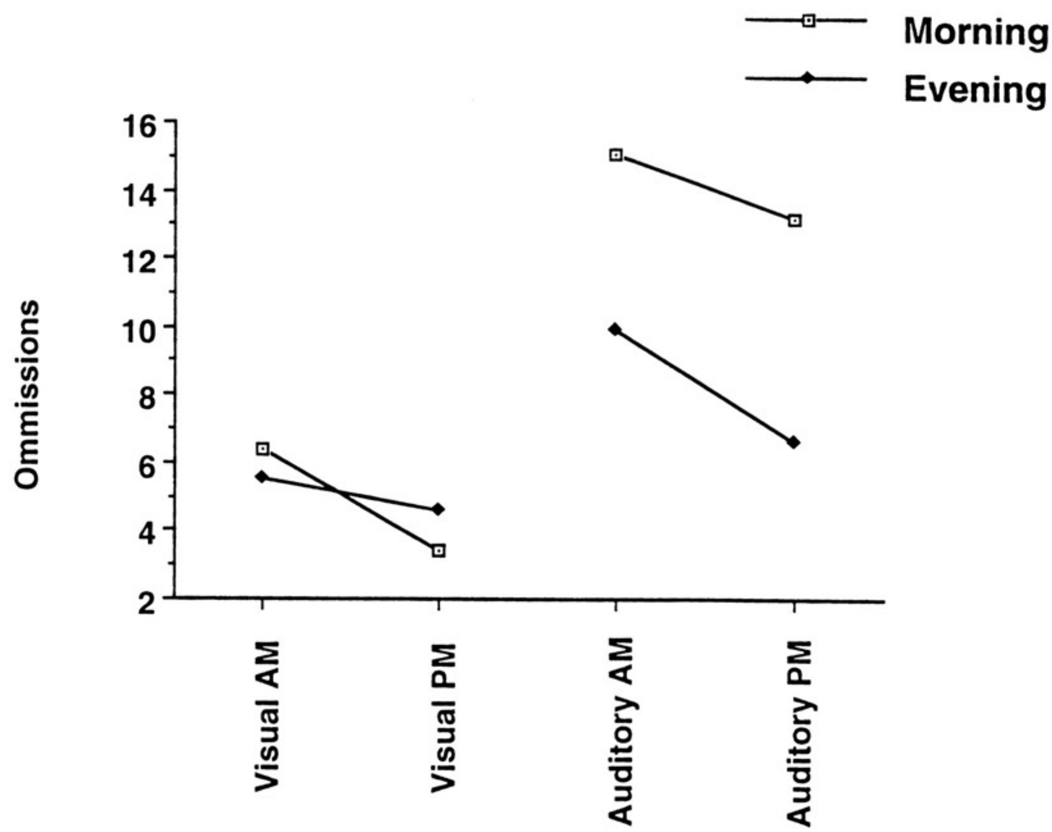

Morning
Evening
30
20
10
0
Incorrect Responses
Visual AM
Visual PM
Auditory AM
Auditory PM

Figure 21. Interaction between circadian type (Morning vs. Evening) and time of day for Continuous Performance Test, number of omissions (top) and mean response time (bottom). Lines do not represent continuous data.


Morning
Evening
16
14
12
10
8
6
4
2
Ommissions
Visual AM
Visual PM
Auditory AM
Auditory PM

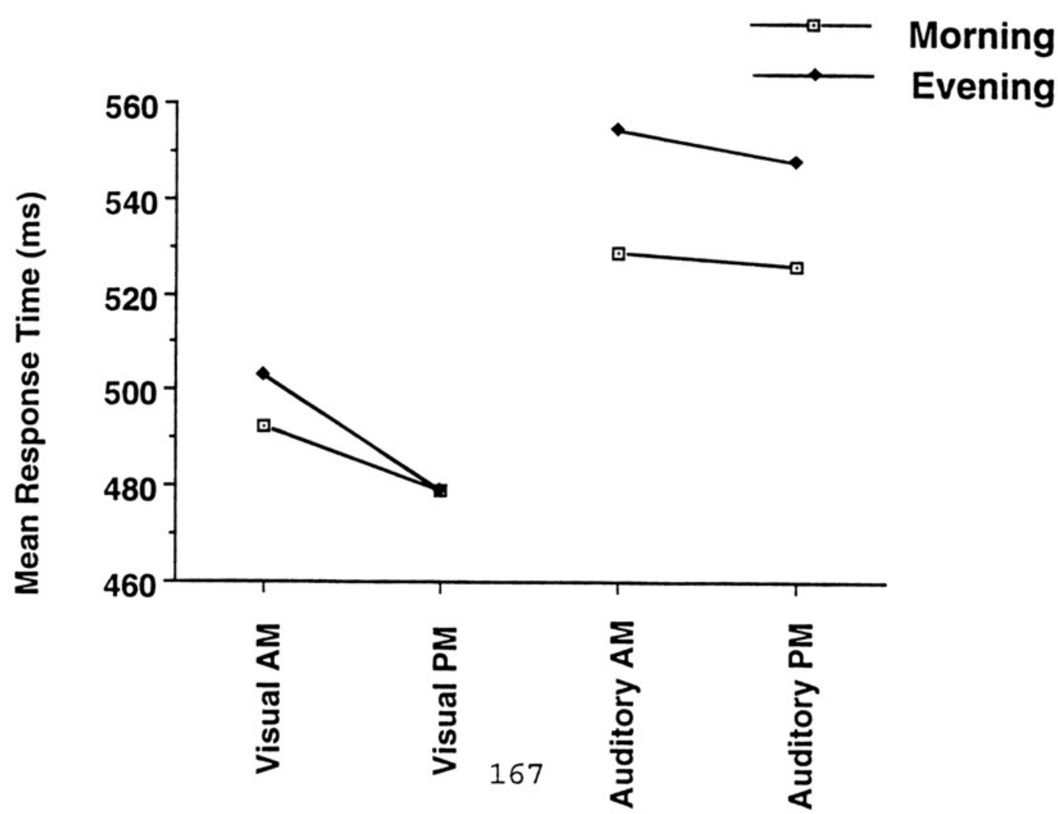
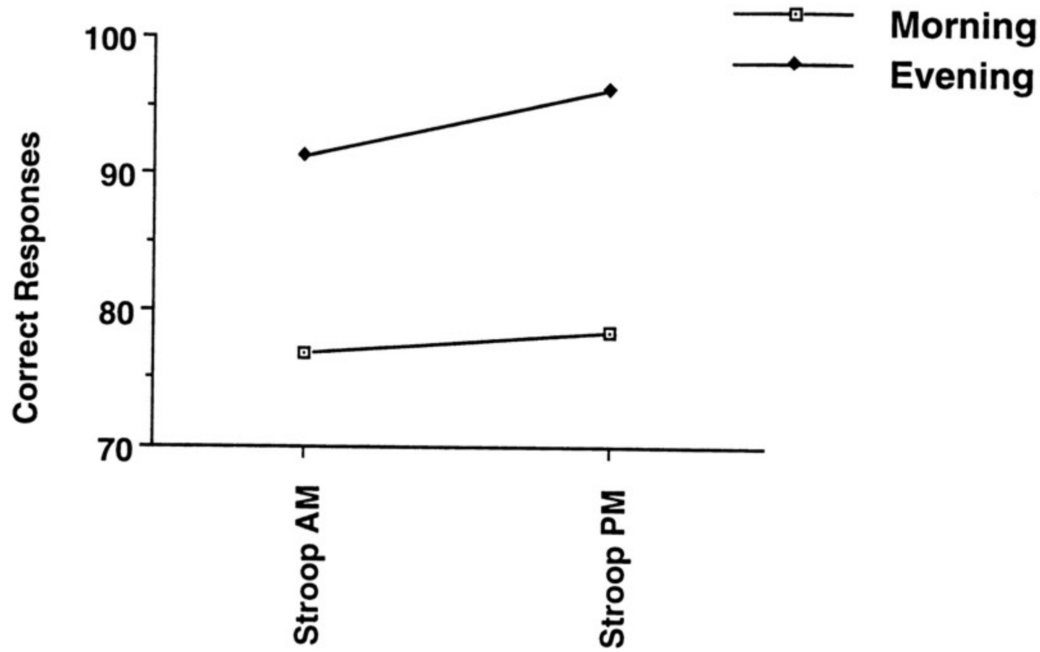

Morning
Evening
560
540
520
500
480
460
Mean Response Time (ms)
Visual AM
Visual PM
Auditory AM
Auditory PM

Figure 22. Interaction between circadian type (Morning vs. Evening) and time of day for the Stroop task, correct responses (top) and reaction time (bottom). Lines do not represent continuous data.


Morning
Evening
100
90
80
70
Correct Responses
Stroop AM
Stroop PM

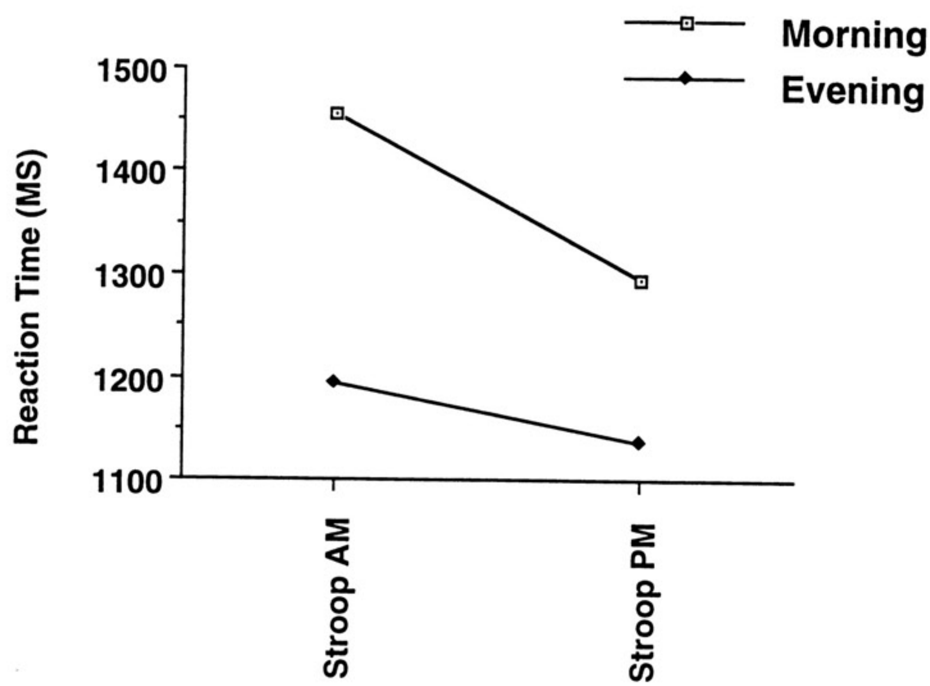
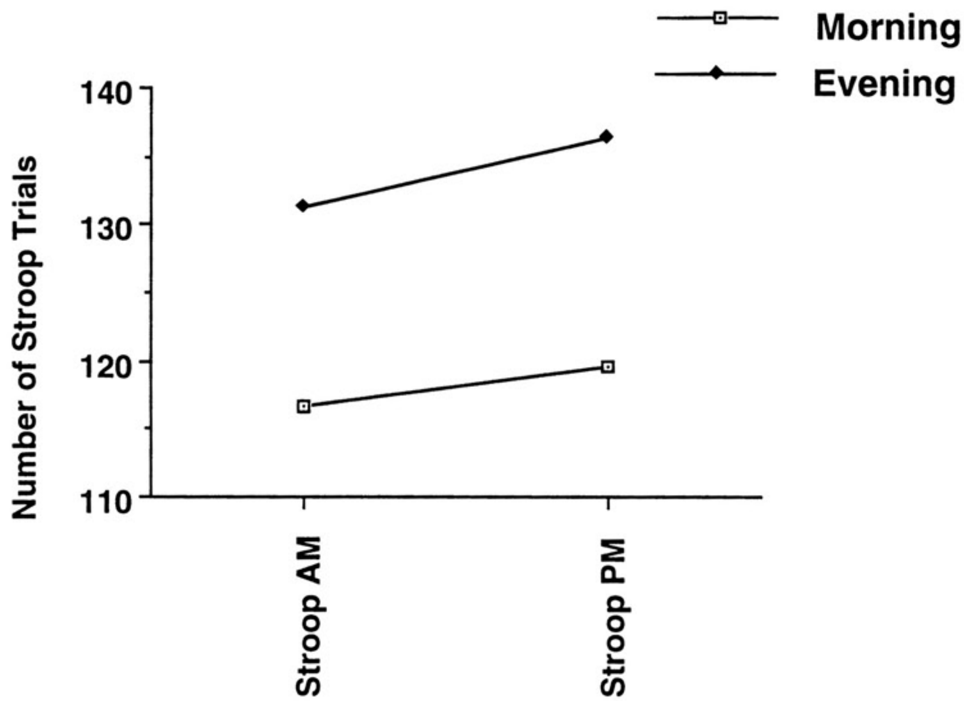
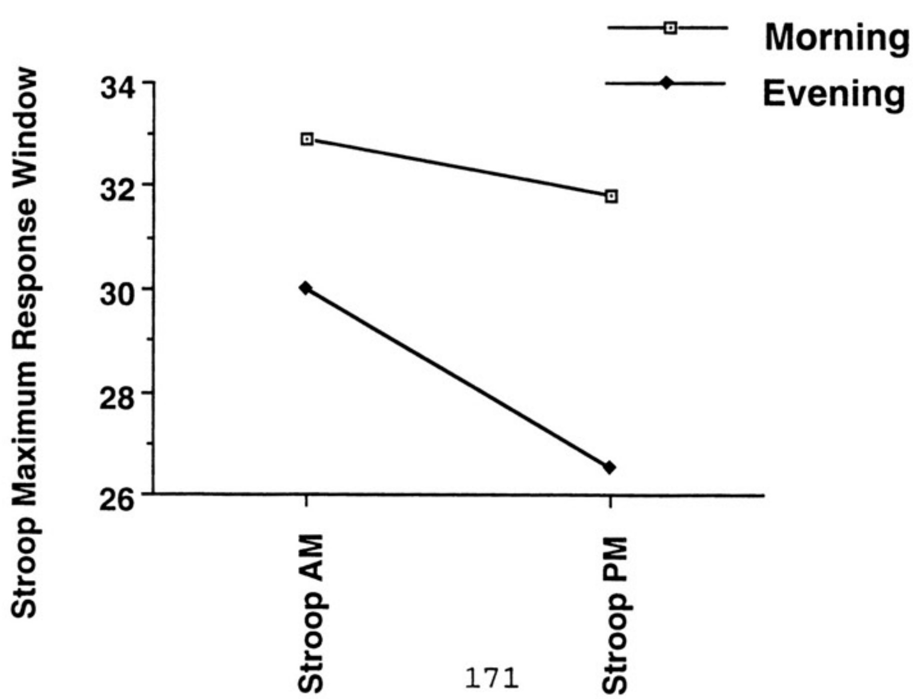

Morning
Evening
1500
1400
1300
1200
1100
Reaction Time (MS)
Stroop AM
Stroop PM

Figure 23. Interaction between circadian type (Morning vs. Evening) and time of day for the Stroop task, number of Stroop trials (top) and maximum response window (bottom). Lines do not represent continuous data.


Morning
Evening
Number of Stroop Trials
140
130
120
110
Stroop AM
Stroop PM


Morning
Evening
Stroop Maximum Response Window
34
32
30
28
26
Stroop AM
Stroop PM

APPENDIX

Telephone Screen

Introduce yourself.
You called in response to our ad...
Do you have a few minutes?

The study involves looking at different physiological responses such as HR and BP during mental and physical tasks. It will involve 2 separate 2.5 hour sessions, one beginning at approximately 7:30 a.m. and the second one beginning at 3:30. Both sessions will occur on a weekday and must occur 3-4 weeks apart.
You will be compensated a total of $50; $15 after the first session and $35 after the second session.

Ask if interested in participating.
If yes, screen.
We need to ask you a few questions to see if you are eligible to participate in the study.

TELEPHONE SCREEN

DATE:__________________

NAME:____

ADDRESS:____

PHONE: (Home)___________________ (Work)____________________

AGE:_______ Height:__________
Weight___________

OCCUPATION:____

WHAT ARE YOUR REGULAR WORK
HOURS?________________________________

EDUCATION
LEVEL____

Assess Morningness/Eveningness:
See attached rMEQ to assess this dimension.
If subject is a Morning or Evening subject, go ahead and continue screening.

Have you participated in any other studies at this university?
(If they have participated in the Nebel/Howell study

exclude them from participation).

Are you currently in the military or are you a veteran?

If current military remind that no compensation can be given during regular work hours. They must take leave in order to participate in the study.

DO YOU HAVE ANY PERMANENT OR CHRONIC HEALTH PROBLEMS (eg. High BP, Asthma, Allergies, Heart Condition, Ulcer, Arthritis, Diabetes, Cancer...), OR ANY PROBLEMS WHICH HAVE LASTED FOR OVER 3 MONTHS: Y / N

IF YES,
SPECIFY:____
____

DO YOU HAVE ANY PHYSICAL DISABILITIES THAT EFFECT GENERAL ACTIVITY LEVELS: Y / N

IF YES,
SPECIFY:____

HAS YOUR HEALTH CHANGED IN THE LAST 6 MONTHS: Y / N

IF YES,
HOW:____

DO YOU TAKE ANY PRESCRIPTION DRUGS: Y / N

IF YES,
WHICH:____

FOR WHAT HEALTH
PROBLEMS:___________________________________

DO YOU TAKE ANY NON-PRESCRIPTION DRUGS: Y / N

IF YES,
WHICH:____

FOR WHAT HEALTH
PROBLEM:____________________________________

DO YOU SMOKE: Y / N (exclude if smoking)

IF YES, HOW MANY CIG./DAY:_____________

HOW OFTEN DO YOUR DRINK CAFFEINATED BEVERAGES:
(caffeinated beverages include coffee, certain teas, colas, Mountain Dew, Mr. Pibb, and Dr. Pepper, (12

ounces = 1 serving)
_______ DAILY (if so how many servings?) _______
_______ EVERY OTHER DAY
_______ AT LEAST ONCE A WEEK
_______ LESS THAN ONCE A WEEK
_______ NEVER
(Exclude if 5 or more servings per day)

WHEN YOU HAVE BEEN UNABLE TO CONSUME CAFFEINE FOR ANY REASON,
DID YOU EXPERIENCE ANY OF THE FOLLOWING SYMPTOMS?

NO **YES**
_____ _____ anxiety
_____ _____ a strong desire to drink caffeinated beverages
_____ _____ drowsiness
_____ _____ fatigue
_____ _____ headache
_____ _____ impaired performance
_____ _____ irritability/frustration/anger
_____ _____ nausea/vomiting
_____ _____ shakiness/trembling
(Exclude if subject has excessive withdrawal symptoms)

DO YOU DRINK BEER OR WINE: Y / N

IF YES, HOW MUCH A WEEK:_______________

DO YOU DRINK ALCOHOLIC BEVERAGES OTHER THAN BEER OR WINE: Y / N

IF YES, HOW MUCH A WEEK:_______________

DO YOU THINK YOU HAVE A DRINKING PROBLEM: Y / N

DO YOU TAKE DRUGS SUCH AS MARIJUANA, COCAINE, ETC: Y / N

ARE YOU CURRENTLY DIETING: Y / N
If yes, how many calories/day ___________

DO YOU EXERCISE REGULARLY: Y / N

IF YES, HOW MANY HOURS A WEEK:__________

ARE YOU CURRENTLY CONSULTING A PSYCHOLOGIST / PSYCHIATRIST: Y / N

IF YES,
WHY:____

DO YOU OR HAVE YOU EVER HAD PROBLEMS SUCH AS DEPRESSION: Y/N

IF FEMALE:

ARE YOU PREGNANT? (If yes, exclude)

ARE YOU TAKING BIRTH CONTROL PILLS? (If yes, exclude)
If eligible:

Set up appointment for 1st session.

Females will be scheduled during days 5 through 11 of the menstrual cycle. If their cycle is regular go ahead and schedule during this time period and then call to confirm. Otherwise have them call on the first day of their period and schedule them at this point.

We will be sending you a sheet with directions and a confirmation of the date and time. We will also be sending instructions on diet and activities for the day of the appointment. We will ask you not to do any strenuous physical exercise such as weight lifting or running the morning of the session. We will also ask you to not drink any caffeinated beverages 3 hours prior to coming to the session.

If A.M.- The instructions you will get in the mail will give you a list of foods for breakfast. You can choose what to eat from the list. The foods will include normal breakfast items such as toast and fruit.
If P.M.- We will want you to eat your normal breakfast. The instructions you will get in the mail will give you a list of foods for lunch. You can choose what to eat from the list. The foods will include normal lunch items such as a sandwich and salads. In addition, we would like you to eat a snack before coming into the lab for the afternoon session.

Reduced Morningness/Eveningness Questionnaire

1. Considering only the times you feel best, at what time would you get up if you were entirely free to plan your day?

AM 5 6 7 8 9 10 11 12PM

7. During the first half-hour after having woken in the morning in the morning, how tired do you feel?

Very tired...................................________

Fairly tired.................................________

Fairly refreshed.............................________

Very refreshed...............................________

10. At what time in the evening do you feel tired and as a result in need of sleep?

PM 8 9 10 11 12AM 1 2 3AM

18. At what time of the day do you think that you feel your best?

12 2 4 6 8 10 12 2 4 6 8 10 12
MIDNIGHT NOON MIDNIGHT

19. One hears about "morning" and "evening" types of people. Which One of these types do you consider yourself to be?

Definitely a "morning" type..................________

Rather more a "morning" type.................._______

Rather more an "evening" type................._______

Definitely an "evening" type.................._______

Consent For Research Participation

Please read carefully.

Title of Study: The effects of task performance on psychological and cardiovascular functioning.
USUHS Protocol R07233: Biobehavioral Triggers of Cardiovascular Disease.

We are studying the effects of task performance on several psychological and physiological functions. In order to do this we will have you answer a number of questions and participate in some tasks. We are asking you to help us by participating in two 2.5 hour sessions in our laboratory. We will pay you $50 for participating in these sessions ($15 after session 1 and $35 after completion of session 2).

We are also interested in learning about your background. We will ask you questions about your health, well-being, and daily activities. We may ask you to complete the following tasks: a color-word coordination task, an arithmetic task, an attention task, a proofreading task, and a hand-grip exercise.

During the time you are in the laboratory, we will be measuring your blood pressure. In order to do this we will attach a cuff like the one in your doctor's office to your non-dominant arm. This cuff is attached to a machine that will cause the cuff to inflate automatically at approximately 2-3 minute intervals at certain time throughout the session. We will also be measuring heart rate throughout the session using EKG leads attached to your chest and abdomen. Respiration rate will also be measured during the session by placing a gauge around the chest which records breathing patterns.

One possible inconvenience or discomfort during this study involves possible frustration during the tasks. If at any time during the study you should choose not to participate in some part of the study, you may do so without penalty. If you decide to participate, you may withdraw or discontinue participation at any time, for any reason, without prejudice. If you have any questions, we expect you to ask us.

Research records of your participation in this study will be maintained by the principal investigator, Dr. David Krantz. Confidentiality is protected to the best extent under law. Your identity will not be traceable by anyone

other than the research team. The data will be published in scientific journals but will not be published in any manner that can identify you.

This study does not entail any physical or mental risk beyond those described above. If, however, you should become uncomfortable during the study, sufficiently uncomfortable that you would like to end the session, tell us. We do not expect this to occur, but if, for any reason, you fell that continuing would constitute a hardship, please tell us and we will end the session.

If you believe that you have suffered any injury or illness as a result of participating in this research, please contact Research Administration, 295-3303, at the University. This office can review the matter with you and may be able to identify resources available to you. Information about possible judicial avenues of compensation is available from the University's Legal Counsel, 295-3028.

If you desire additional information about this experiment, either about the rationale for the study, its findings, or about your rights as a participant, you may contact Linda Nebel or Sandra Jochum in the Department of Clinical and Medical Psychology, 295-3270, to obtain information about it. In this way, you may make your participation in our research a more informative and educational experience. We welcome your comments and suggestions, and appreciate you willingness to help us.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE INDICATES THAT, HAVING READ THE ABOVE INFORMATION, YOU HAVE DECIDED TO PARTICIPATE.

Date Signed _______________ Subject Initials _______________

Subject Printed Name _______________ Signature of Subject _______________

I was present during the explanation referred to above, as well as during the volunteer's opportunity to ask questions. I hereby witness the volunteer's signature.

Investigator/Printed Name _______________ Investigator/Signature _______________

Visual Analog Scale

Circle one:

Rest 1	Math/Stroop	Subject number_____
Rest 2	CPT	Date_____
Rest 3	Proofreading	Time_____
Handgrip		

Instructions: Below are words which describe the feelings people have. Please read each one carefully and rate how much you have had that feeling during the past 10 minutes, including now. You may mark anywhere on each line.

	Not at all	Extremely
Anxious	______________________________	
Frustrated	______________________________	
Interested	______________________________	
Tired	______________________________	
Happy	______________________________	
Depressed	______________________________	
Angry	______________________________	
Bored	______________________________	
Challenged	______________________________	
Irritated	______________________________	

Daily Activities Questionnaire

INSTRUCTIONS

This questionnaire is designed to determine what your activities have been like over the past 24 hours (or in some cases, the past week). Please read over each question carefully and answer it as accurately as you can. Some of the items will ask you to fill in a response, while others will ask you to rate the question on a scale. Please answer all of the questions.

THANK YOU.

1. What time is it now? ________________

2. Did you consume any caffeinated beverages (for example, coffee, colas, tea, etc.) in the last 24 hours? (circle one)

   YES NO

   If so,
   How many caffeinated beverages did you consume in the past 24 hours? ________________

   At what time, in the last 24 hours, did you last consume a caffeinated beverage? ___________________

3. Did you smoke (cigarettes, cigars, etc.) in the last 24 hours? (circle one)

   YES NO

   If so,
   How many cigarettes did you smoke in the past 24 hours?
   ____

   At what time, in the last 24 hours, did you last smoke a cigarette? ___________________

4. What did you eat for breakfast this morning? (list items)

   ____

____

5. At what time did you eat breakfast? ____________________

6. Have you eaten anything since breakfast? (circle one)

YES NO

If so,
What have you eaten? ______________________________

____

When was the last time you ate? ______________

7. At what time did you fall asleep last night? __________

8. At what time did you wake up this morning? ____________

9. How many hours of sleep did you get last night? ________

10. Compared to your normal sleep, was this amount of sleep ...? (circle one)

(1)	(2)	(3)	(4)	(5)
much less		average		much more

11. How was the quality of your sleep last night? (circle one)

(1)	(2)	(3)	(4)	(5)
very poor		average		much more

12. How did you feel upon awakening this morning? (circle one)

(1)	(2)	(3)	(4)	(5)
very tired		average		very refreshed

13. Do you regularly *engage in physical exercise?* (circle one)

YES NO

If so,
What type of physical exercise do you engage in regularly?

____

How many times per week, and for how long, do you spend in physical exercise?

____

14. Did you exercise in the last 24 hours? (circle one)

YES NO

If so,
What physical exercise did you engage in during the last 24 hour period? ______________________

At what time, in the last 24 hours, did you last engage in physical exercise? ______________

15. Compared to what is normal for you, what was your physical activity level in the past 24 hours? (circle one)

(1)	(2)	(3)	(4)	(5)
much less		average		much more

16. Since yesterday at this time, how much time did you spend in recreational activity?

____

17. How many hours, in the last 24, did you spend working (for example: job, family/home responsibilities, etc.)?

____

18. Compared to what is normal for you, was your level of activity in the last 24 hours ...? (circle one)

(1)	(2)	(3)	(4)	(5)
much less		average		much more

19. Did anything happen in the past <u>24 hours</u> that you found distressing? (circle one)

YES NO

If so,
What was the distressing event?__________________________

____

20. Did anything happen in the past <u>7 days</u> that you found distressing? (circle one)

YES NO

If so,
What was the distressing event?__________________________

21. Compared to what is normal for you, how stressful were the last <u>7 days</u>? (circle one)

(1)	(2)	(3)	(4)	(5)
much less		average		much more

22. Compared to what is normal for you, how stressful were the last <u>24 hours</u>? (circle one)

(1)	(2)	(3)	(4)	(5)
much less		average		much more

23. Do you feel that anything unusual has occurred in the past 24 hours that might affect your performance during today's tasks? (circle one)

YES NO

If so, what? ____

____

____